

UNDERSTANDING POLYESTER RESIN PROCESSING:
THE EFFECT OF AMBIENT TEMPERATURE ON THE FINAL PART

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Co-Director of Advanced Materials Manufacturing MEL Program, UBC

Co-Director of Knowledge in Practice Centre, CKN

- Ph.D. and M.A.Sc. in Composite Materials Engineering
- Over 15 years experience in industry and academia working on polymer matrix composites in aerospace, automotive, marine, energy, recreation and others
- Experience working with over 150 companies from SME to major international corporations
- Expertise in liquid composite moulding and thermal management

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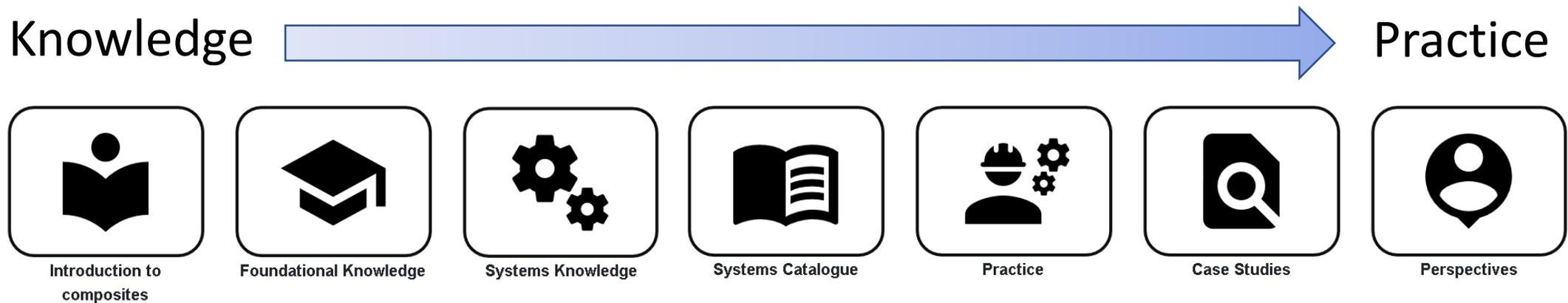
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WEBINARS



KNOWLEDGE IN PRACTICE CENTRE (KPC)

- A freely available online resource for composite materials engineering:
compositeskn.org/KPC
- Focus on practice, guided by foundational knowledge and a systems-based approach to thinking about composites manufacturing



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Perspectives - A8



Welcome to the Perspectives volume. This volume is primarily based on multimedia content and serves as a bridge for linking what you have learned in the other volumes of the Knowledge in Practice Centre out to what other practitioners are doing in their projects and research. The three types of content linked below include presentations, interviews, and *Application and Impact Mobilization* (AIM) event recordings. Presentations and interviews are the primary sections linking out to external perspectives on composites, while the AIM event recording section contains CKN's perspective on how to apply composites knowledge.

Refer to the [Level I](#) view to navigate to the perspectives content quickly, or refer to the [Level II](#) view to navigate to the perspectives content with additional context. [Level II](#) provides more information on the relationship between know-how & know-why, and why it is important to protect the fundamentals of any processes or conventions already in place.

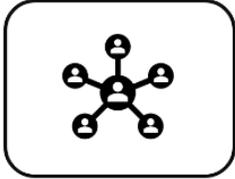
Level I Level II



Presentations



Interviews
[Read more](#)



AIM Event Recordings

CKN Knowledge in Practice Centre

Welcome

Welcome to the CKN Knowledge in Practice Centre (KPC). The KPC is a resource for learning and applying scientific knowledge to the practice of composites manufacturing. As you navigate around the KPC, refer back to the information on this right-hand pane as a resource for understanding the intricacies of composites processing and why the KPC is laid out in the way that it is. The following video explains the KPC approach:



Understanding Composites Processing

The Knowledge in Practice Centre (KPC) is centered around a structured method of thinking about composite material manufacturing. From the top down, the hierarchy consists of:



TODAY'S TOPIC:

*Understanding Polyester Resin Processing:
The effect of ambient temperature on the final part*

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To learn more about thermosetting resins watch:
<https://compositeskn.org/KPC/A122> Webinar Session 3

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OUTLINE AND LEARNING OBJECTIVES

Outline

- Introduction to polyester resin
- Curing polyester
 - Degree of cure
 - Heat of reaction
 - T_g
 - Gel time
- Polyester in the context of MSTEP
- Experimental study
- Industrial case study
- Managing the cure

Learning Objectives

- Understand how polyester resins cure
- Understand the parameters that effect cure
- Understand the effect of ambient temperature on the cure of polyester resin
- Understand what can be done to control the cure

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INTRODUCTION

- Where does polyester resin fit on the composites landscape?
 - ***Most commonly used matrix for thermoset composites***
 - Advantages
 - Economical
 - Flexible cure process
 - Fast cure time
 - Disadvantages
 - Lower material properties than alternatives (epoxy)
 - Low Tg
 - Health and safety issues
 - Higher cure shrinkage



Polyester resin
(One part plus initiator)

INTRODUCTION

- Where does polyester resin fit on the composites landscape?
 - Typically used with glass fibre, rarely with carbon fiber
 - Common applications:
 - Boats/marine
 - Turbine blades
 - Electrical equipment
 - Industrial applications
 - Water slides
 - Truck canopies
 - Pipes/plumbing



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To learn more about polyester resin watch:
<https://compositeskn.org/KPC/A122> Webinar Session 3

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INTRODUCTION

- Common manufacturing processes
 - Hand (wet) layup
 - Spray up
 - Infusion
 - LRTM
 - Pultrusion



Wet/hand layup



Infusion



LRTM



Spray up

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To learn more about processes watch:

<https://compositeskn.org/KPC/A124> Webinar Session 5

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INTRODUCTION

- Common manufacturing processes
 - Hand (wet) layup
 - Spray up
 - Infusion
 - LRTM
 - ~~Pultrusion~~



Wet/hand layup



Infusion



LRTM



Spray up

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To learn more about processes watch:

<https://compositeskn.org/KPC/A124> Webinar Session 5

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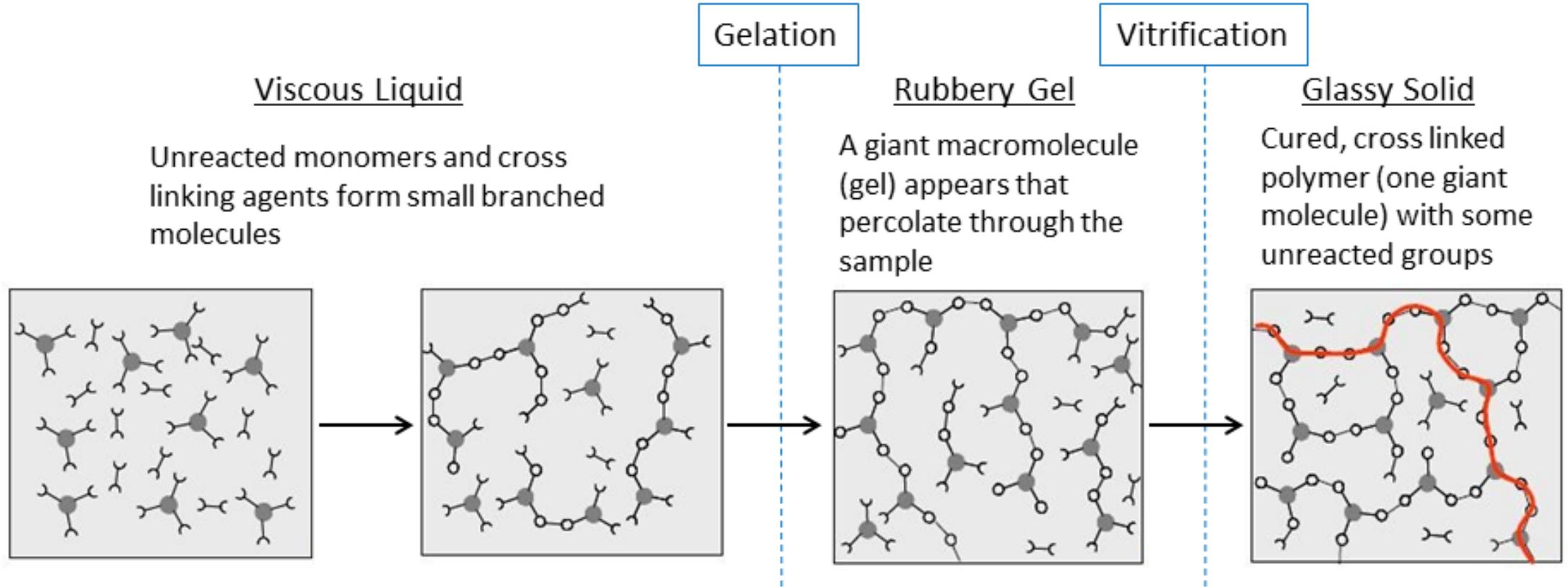


INTRODUCTION

- What is typically common to these processes?
 - Ambient curing (ie. cured by leaving at ambient temperatures rather than using active curing)
 - Minimal/no thermal management
- What does this mean for the manufacturer?
 - Less control over outcomes such as:
 - Degree of cure (DOC)
 - T_g
 - Mechanical properties



POLYESTER RESIN CURING



POLYESTER RESIN CURING

- Polyester is a thermoset resin
 - Goes through an irreversible *exothermic* chemical reaction – ‘the cure’ or ‘curing’
- The cure begins when an initiator is added to the resin
- The rate of cure is a function of temperature
- The higher the temperature, the faster the reaction will generate heat, which increases the temperature further
- The faster the reaction, the less working/gel time

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<https://compositeskn.org/KPC/A103> - Polyester Resin
<https://compositeskn.org/KPC/A162> - Curing Thermoset Resins

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POLYESTER RESIN CURING

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- The higher the temperature, the faster the reaction will generate heat, which increases the temperature further
- The faster the reaction, the less working/gel time

Important to remember that even though the ambient temperature is $\sim 20^{\circ}\text{C}$, the temperature that the material experiences is likely much different

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POLYESTER RESIN CURING

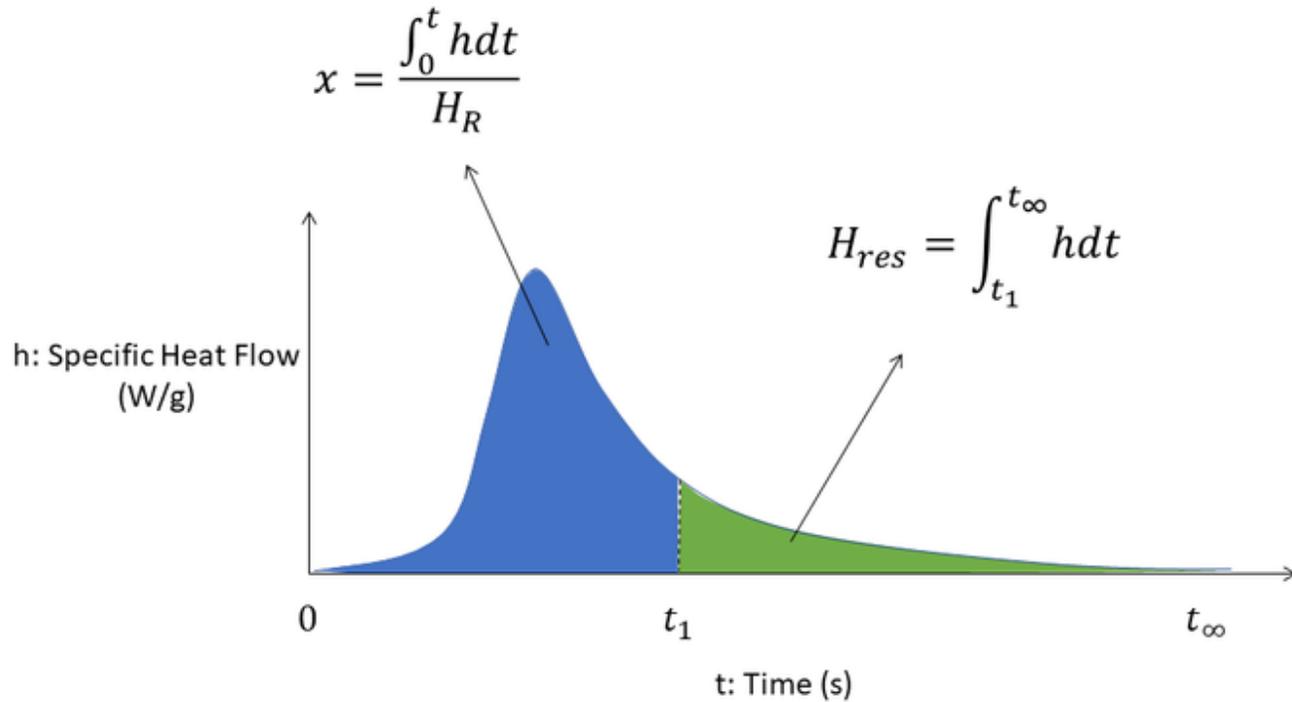
- What properties and outcomes of the cure are we interested in?
 - *Degree of cure, (DOC)*
- Heat of reaction is used to measure DOC

$$x = 1 - \frac{H_{res}}{H_R}$$

Where: $x = DOC (0-1)$

H_{res} = residual heat of reaction

H_R = total heat of reaction



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POLYESTER RESIN CURING

- DOC effects the performance of a composite
- Strength typically increases as DOC increases
- Resistance to chemicals and moisture ingress increases as DOC increases
- Glass transition temperature, T_g indicates when a polymer changes from glassy to rubbery
- T_g increases as DOC increases
 - -> Which relates to it's max operating temperature

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<https://compositeskn.org/KPC/A104> - DOC, T_g
<https://compositeskn.org/KPC/M101> – Gel time

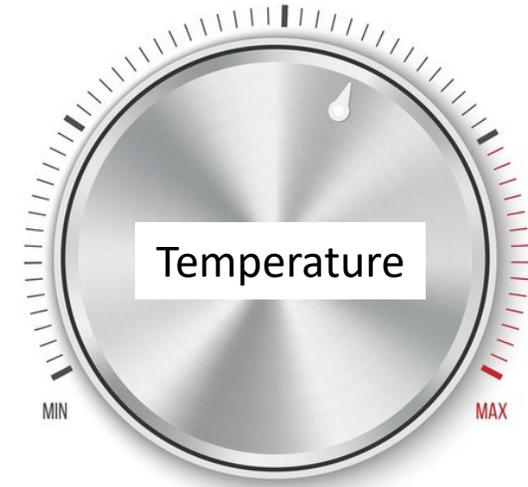
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POLYESTER RESIN CURING

- Typical curing control knobs:



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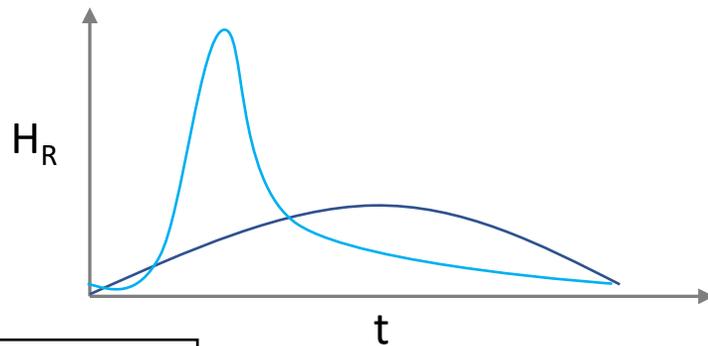
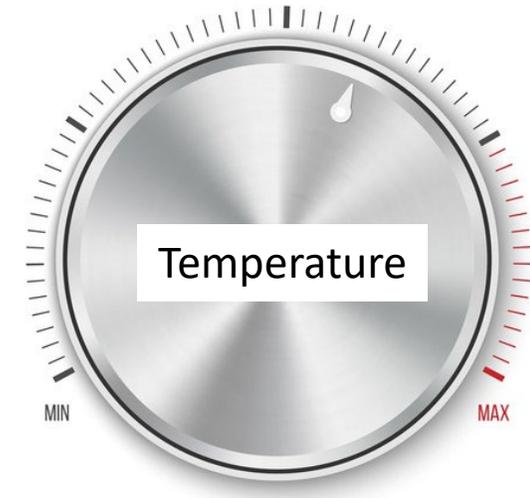
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POLYESTER RESIN CURING

- Typical curing control knobs:



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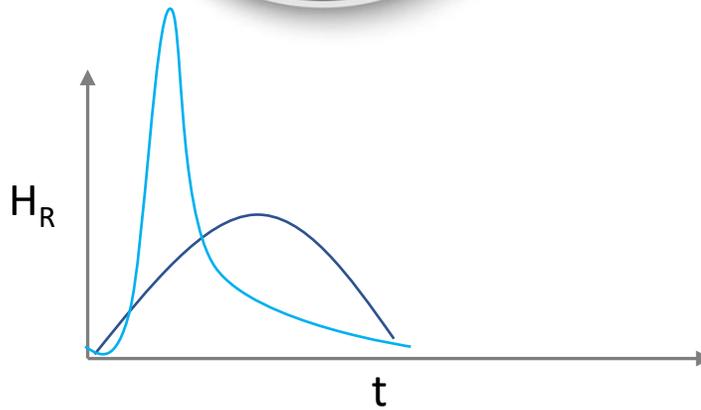
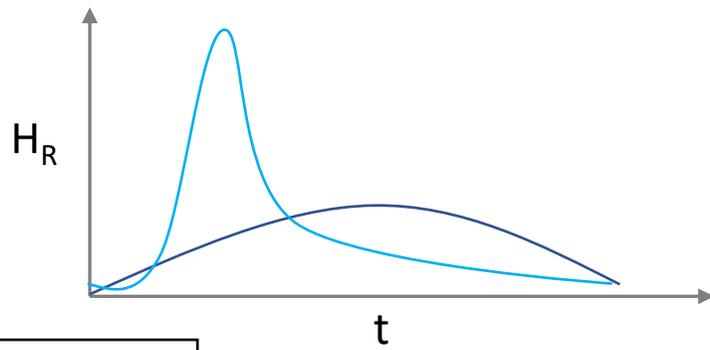
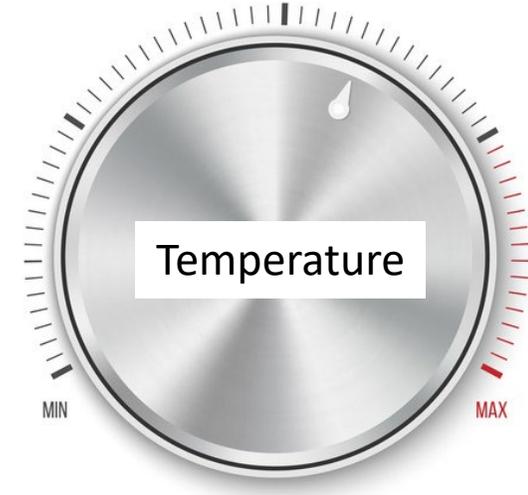


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POLYESTER RESIN CURING

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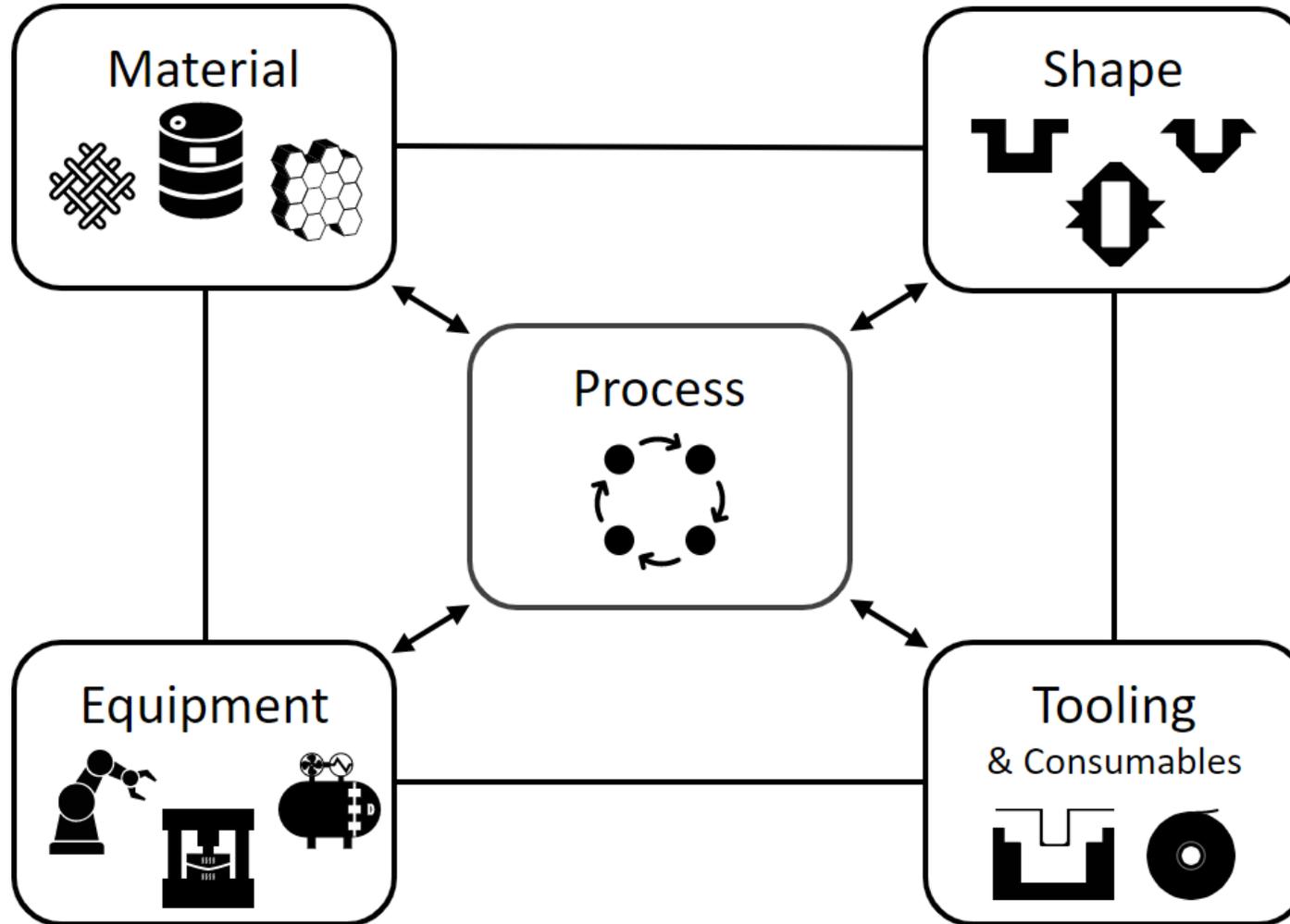


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POLYESTER RESIN CURE IN CONTEXT OF MSTEP



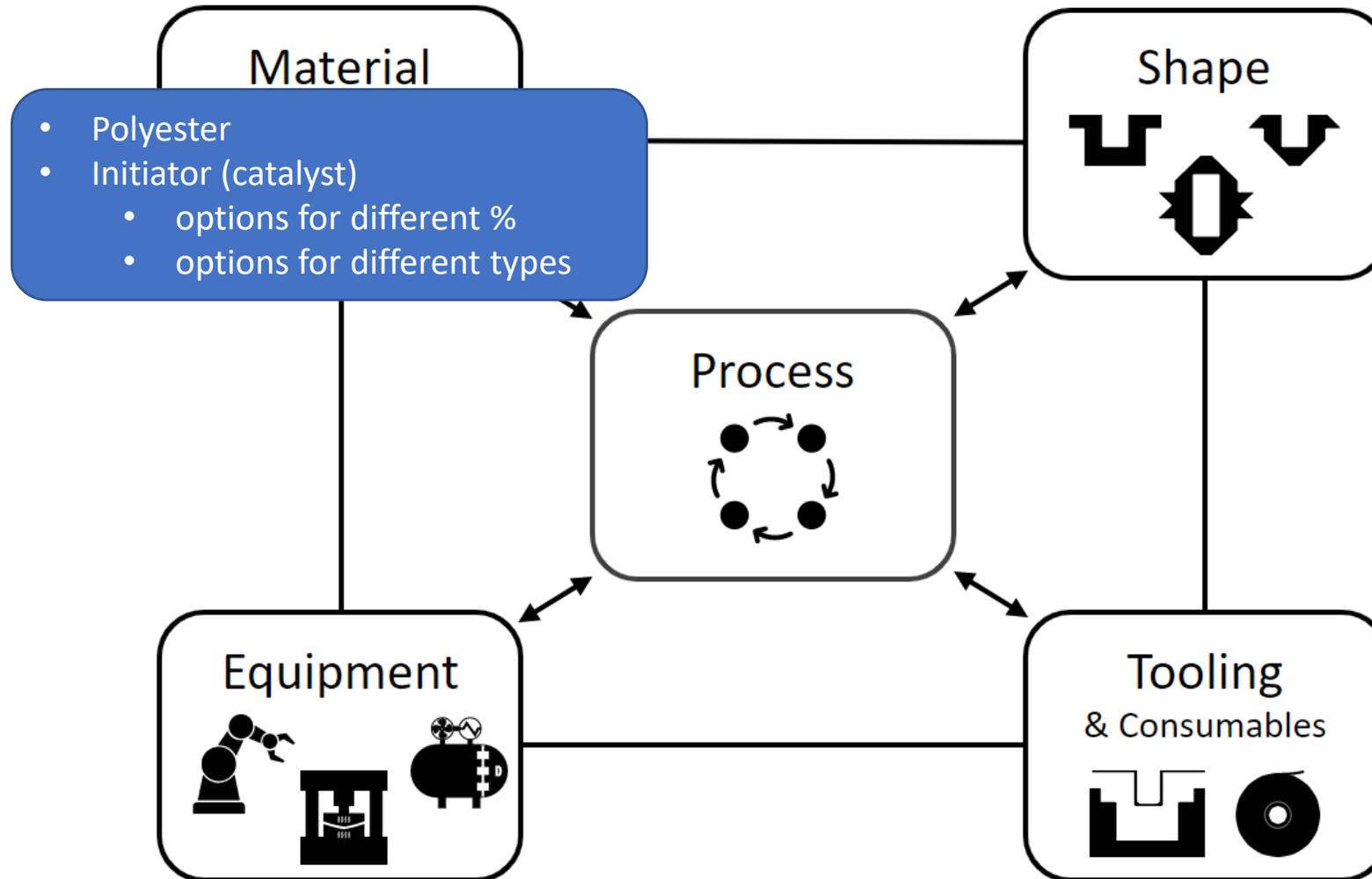
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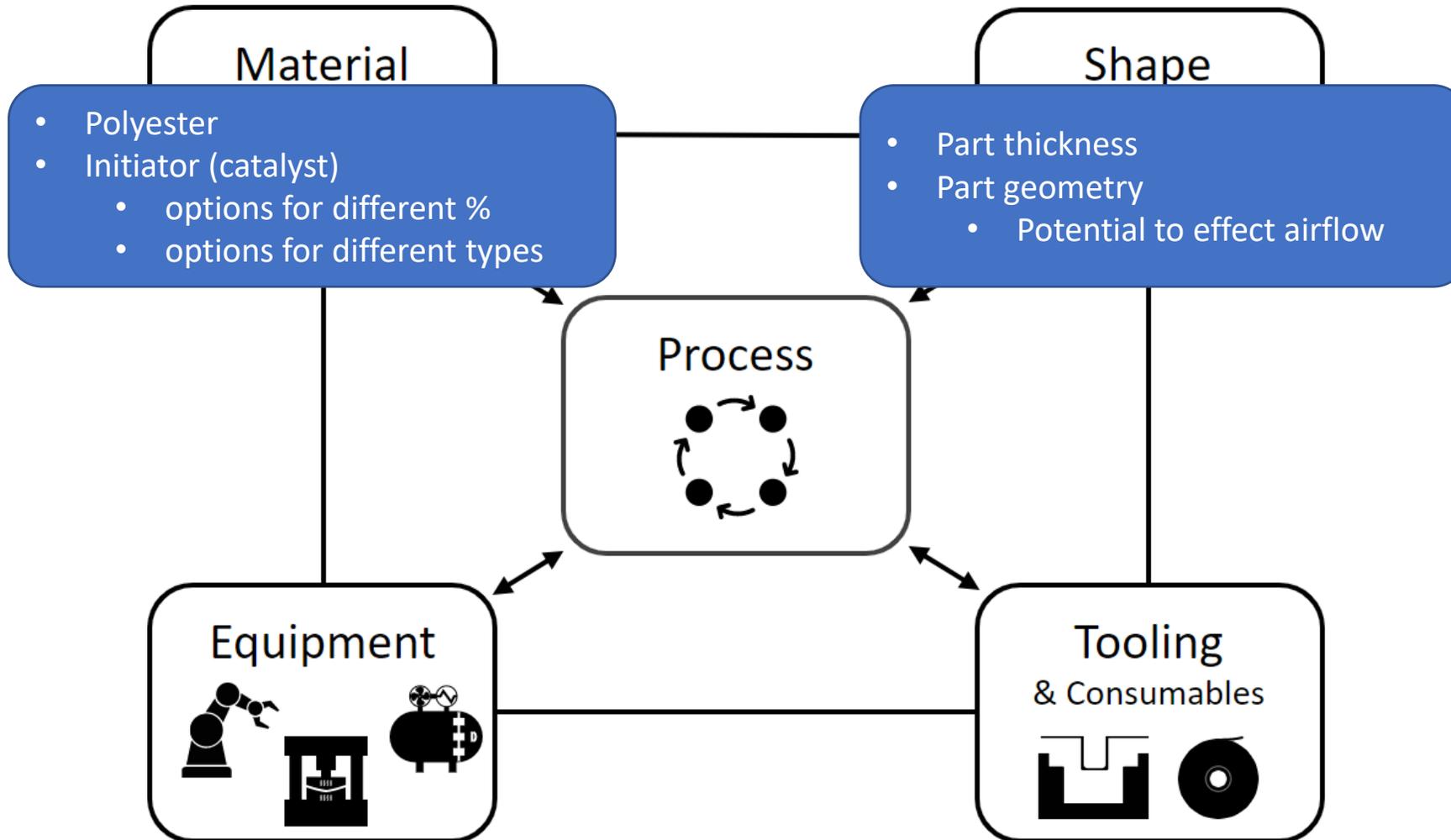
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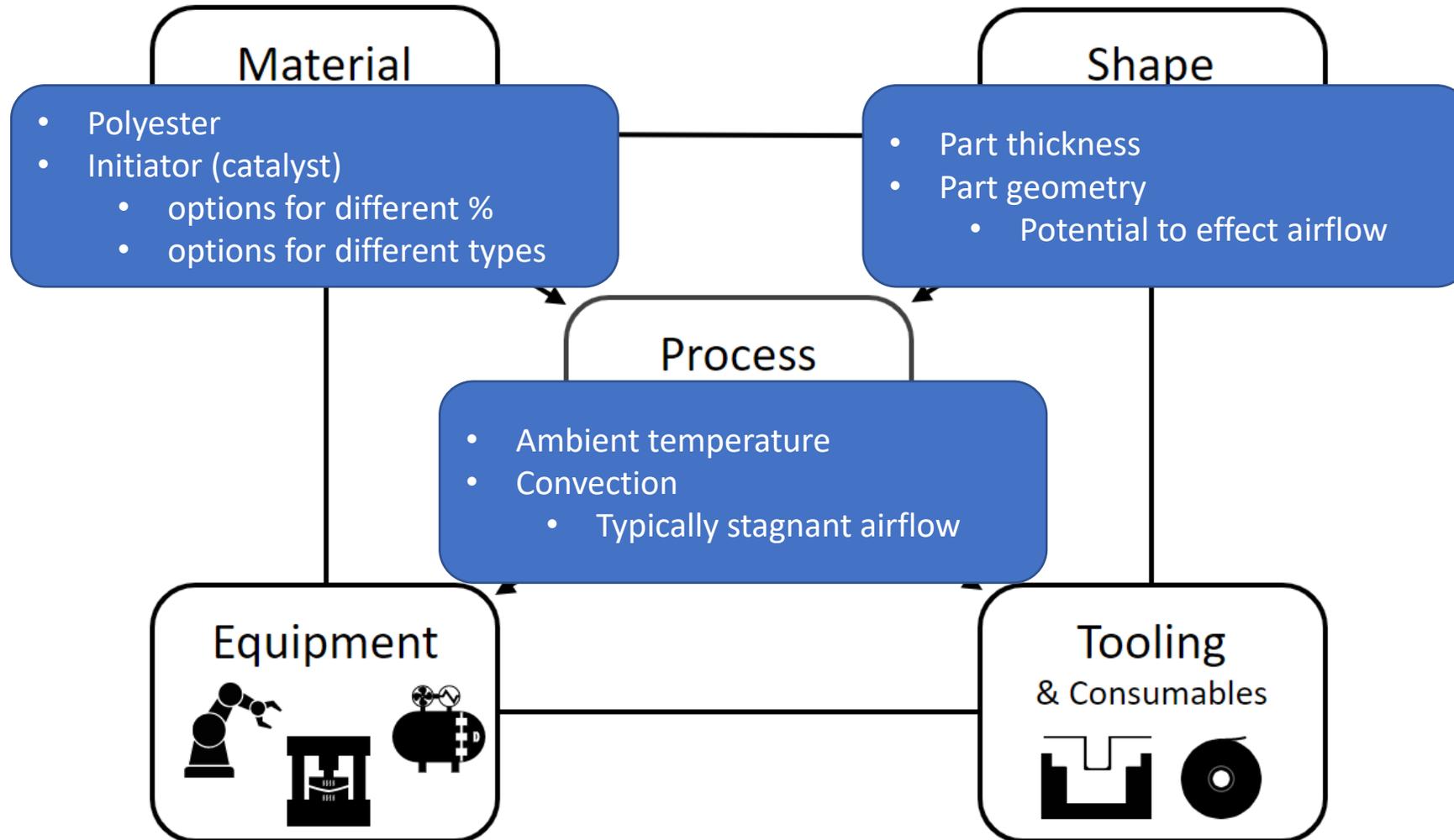
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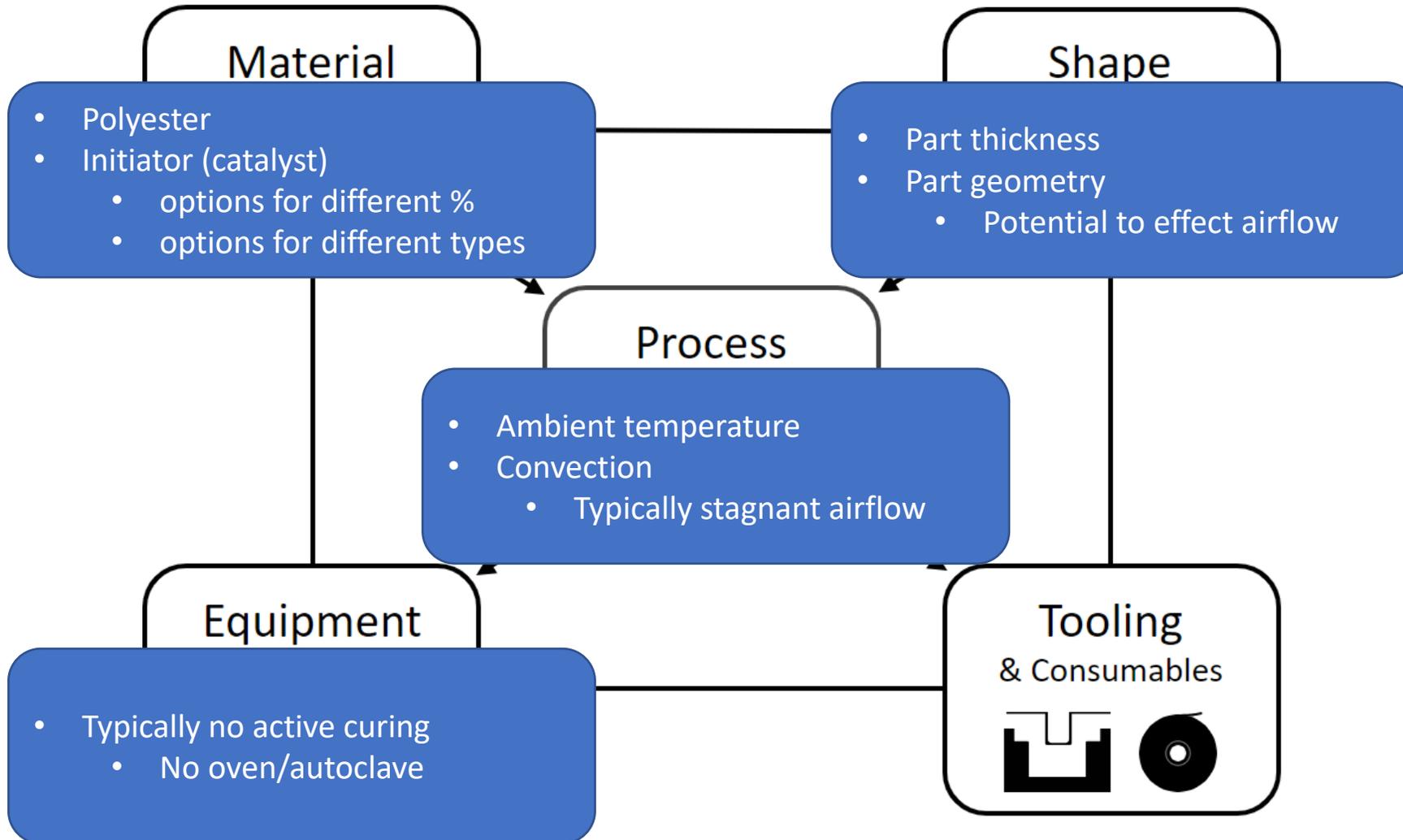
POLYESTER RESIN CURE IN CONTEXT OF MSTEP



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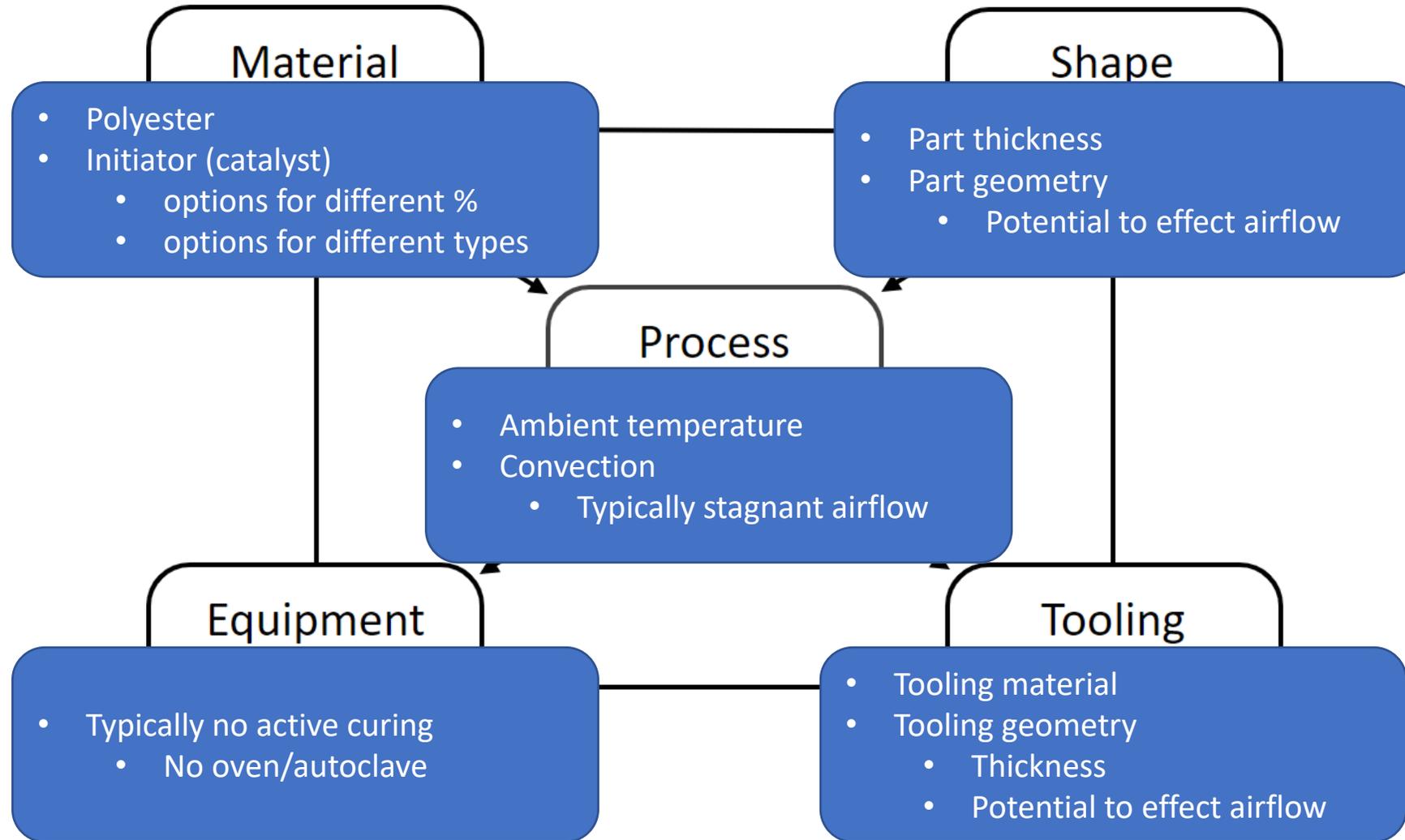
POLYESTER RESIN CURE IN CONTEXT OF MSTEP



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POLYESTER RESIN CURE IN CONTEXT OF MSTEP



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POLYESTER RESIN CURE SIMULATION

Unless otherwise stated:
 6 mm composite part
 Aropol polyester resin
 1.25% MEKP
 6 mm composite tool
 $h = 10 \text{ W/m}^2\text{K}$
 20°C ambient air

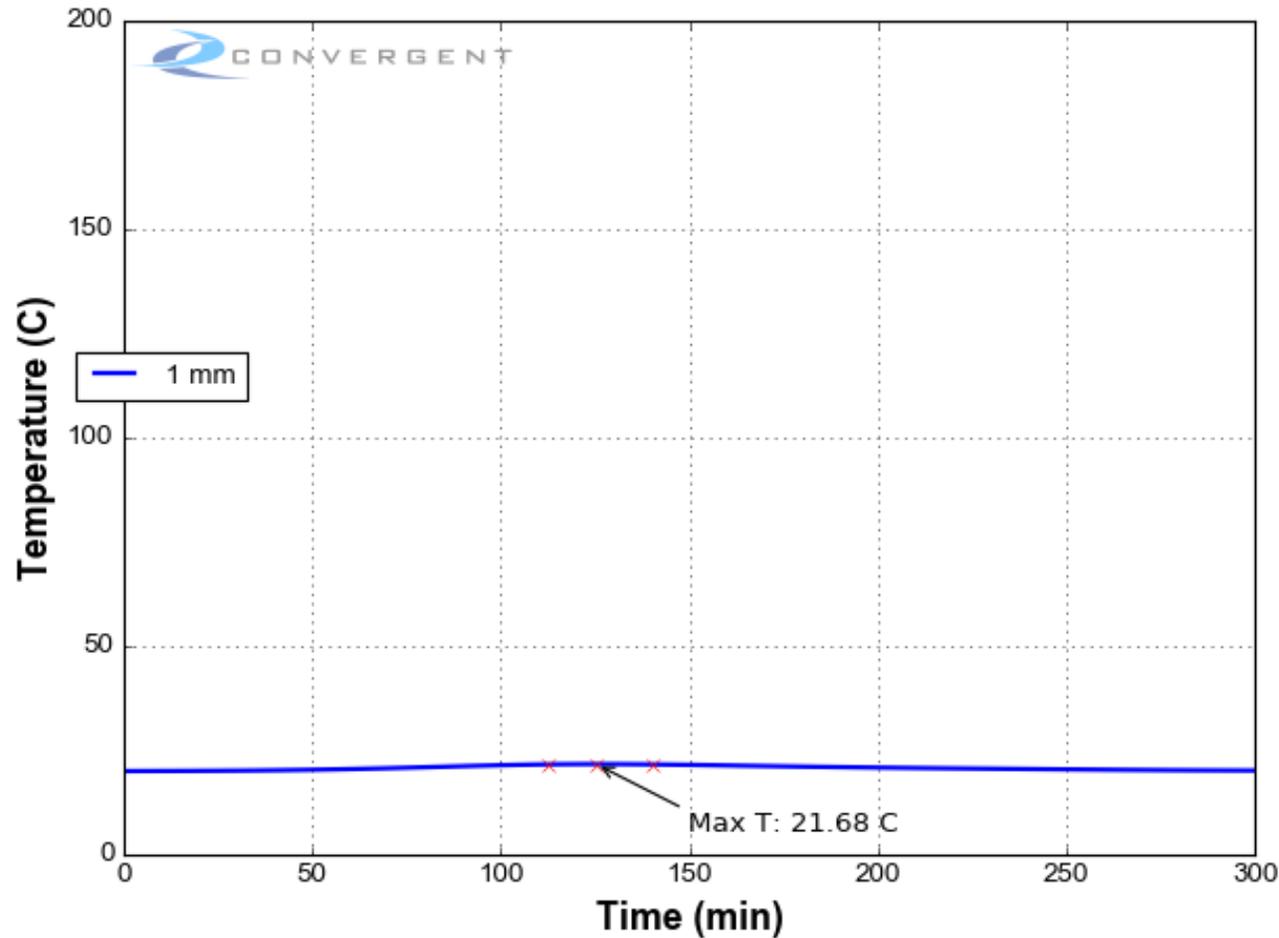
- We'll use 1D simulation to explore various parameters:
 - Part thickness
 - Airflow (convection)
 - Tooling material
 - Tooling thickness



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- Part thickness



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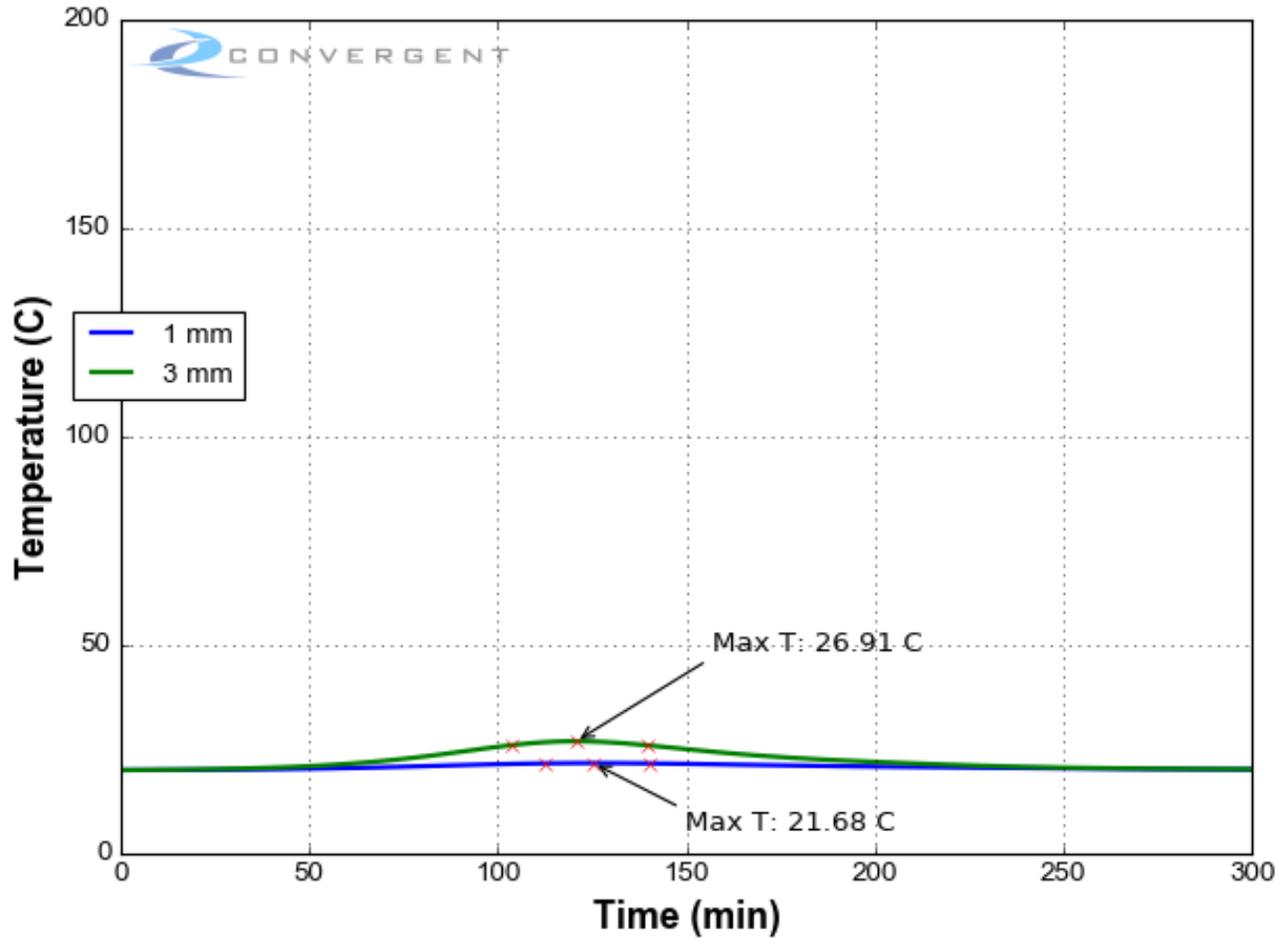
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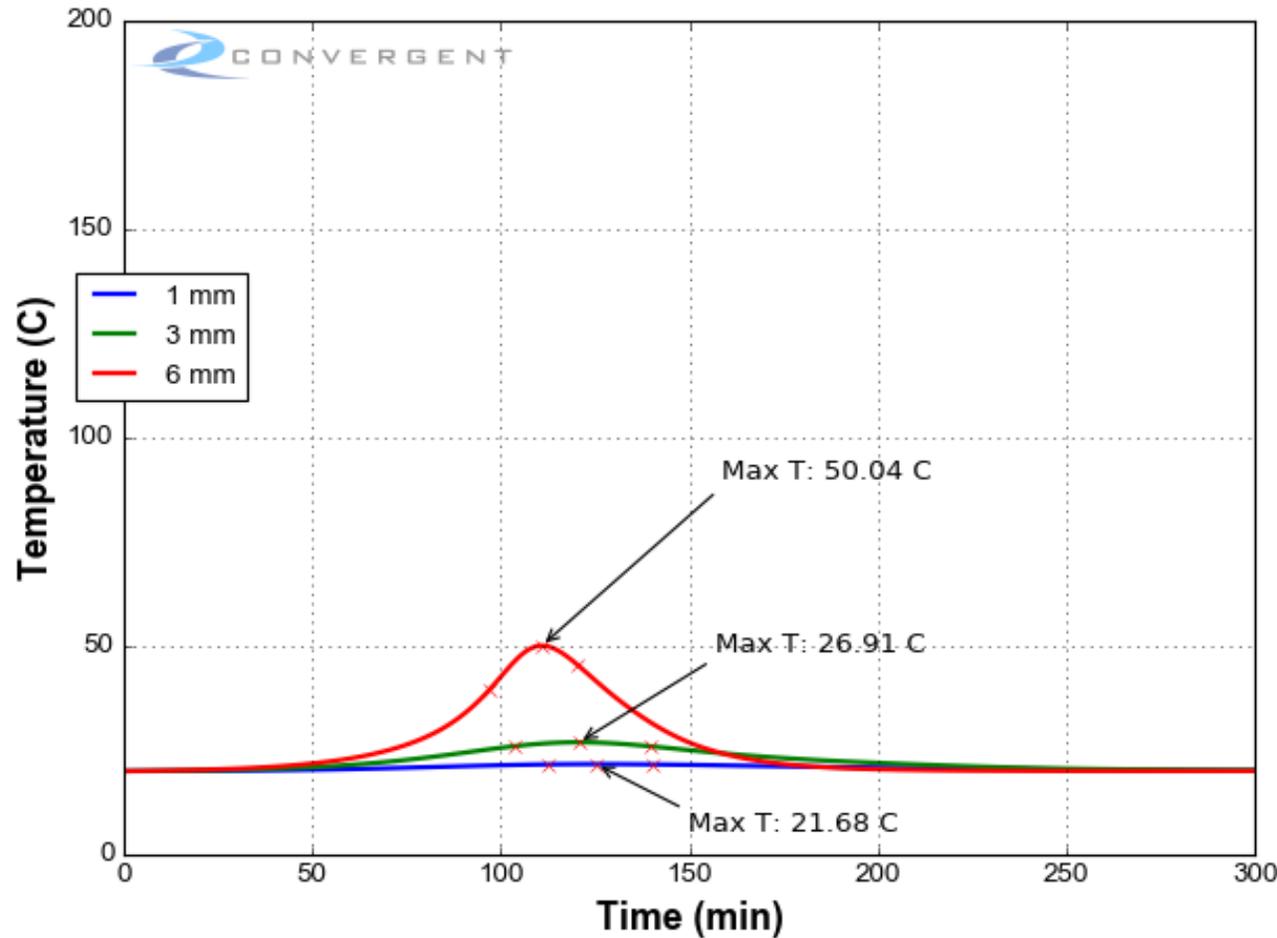
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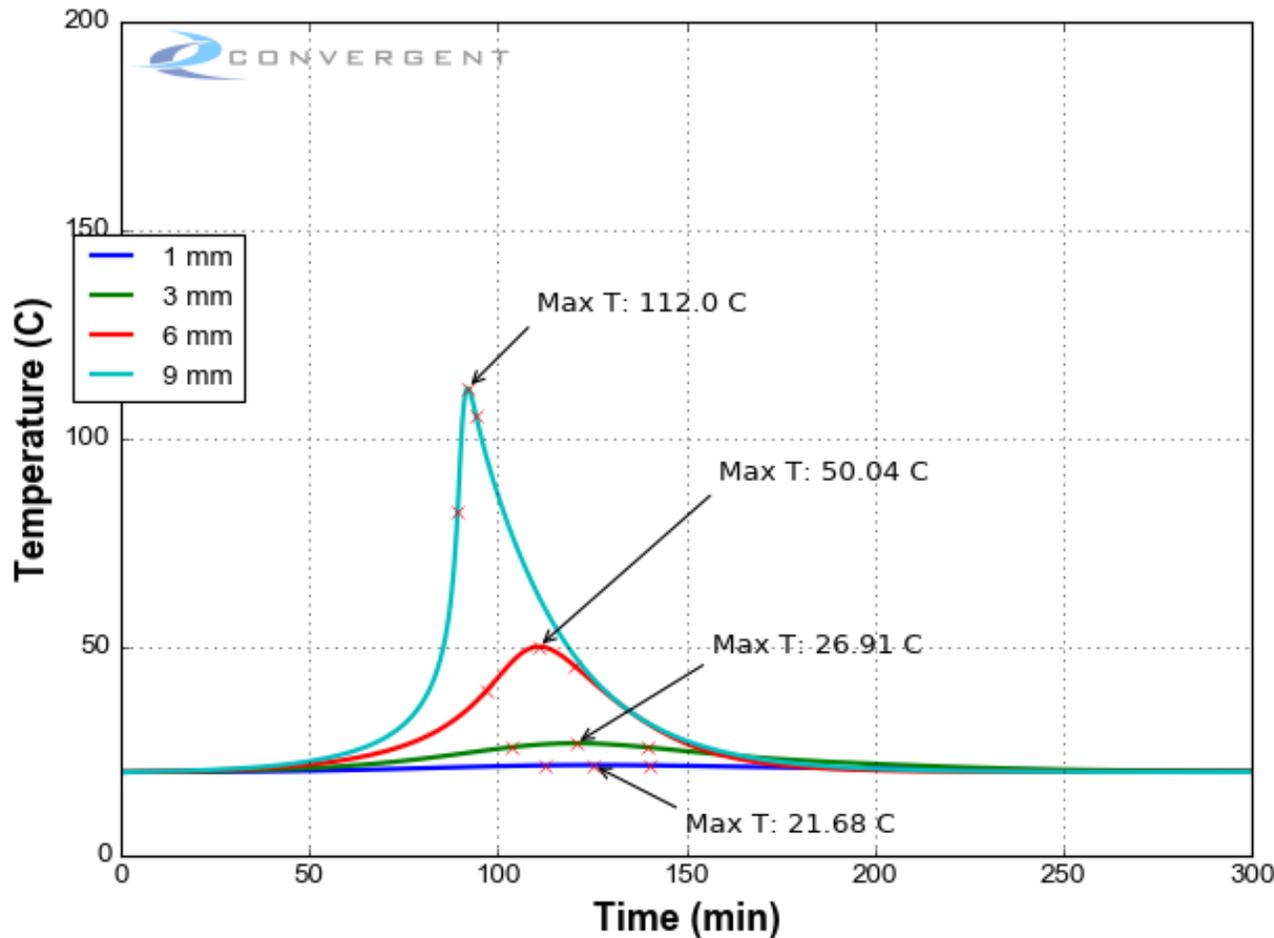
- Part thickness



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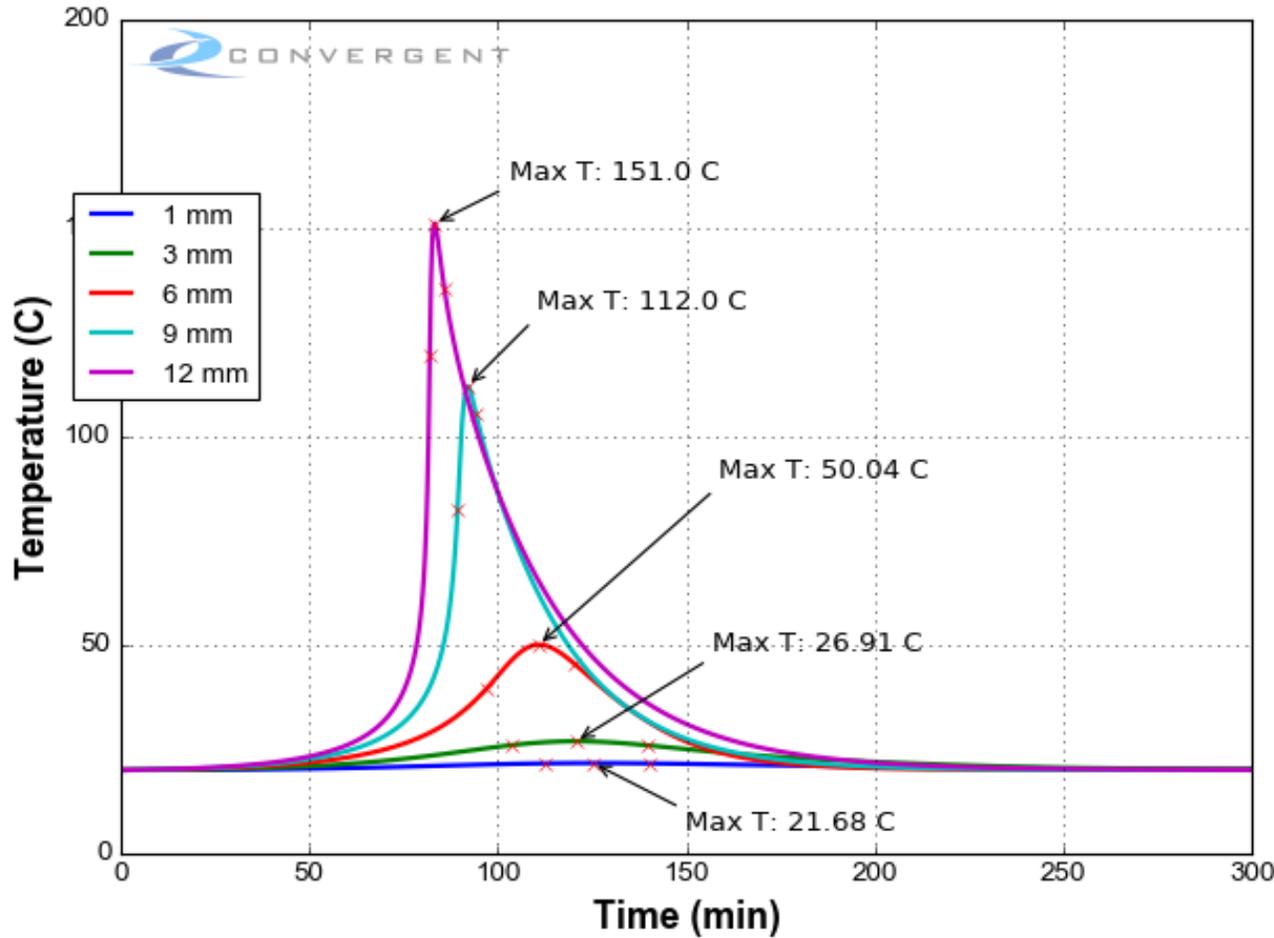
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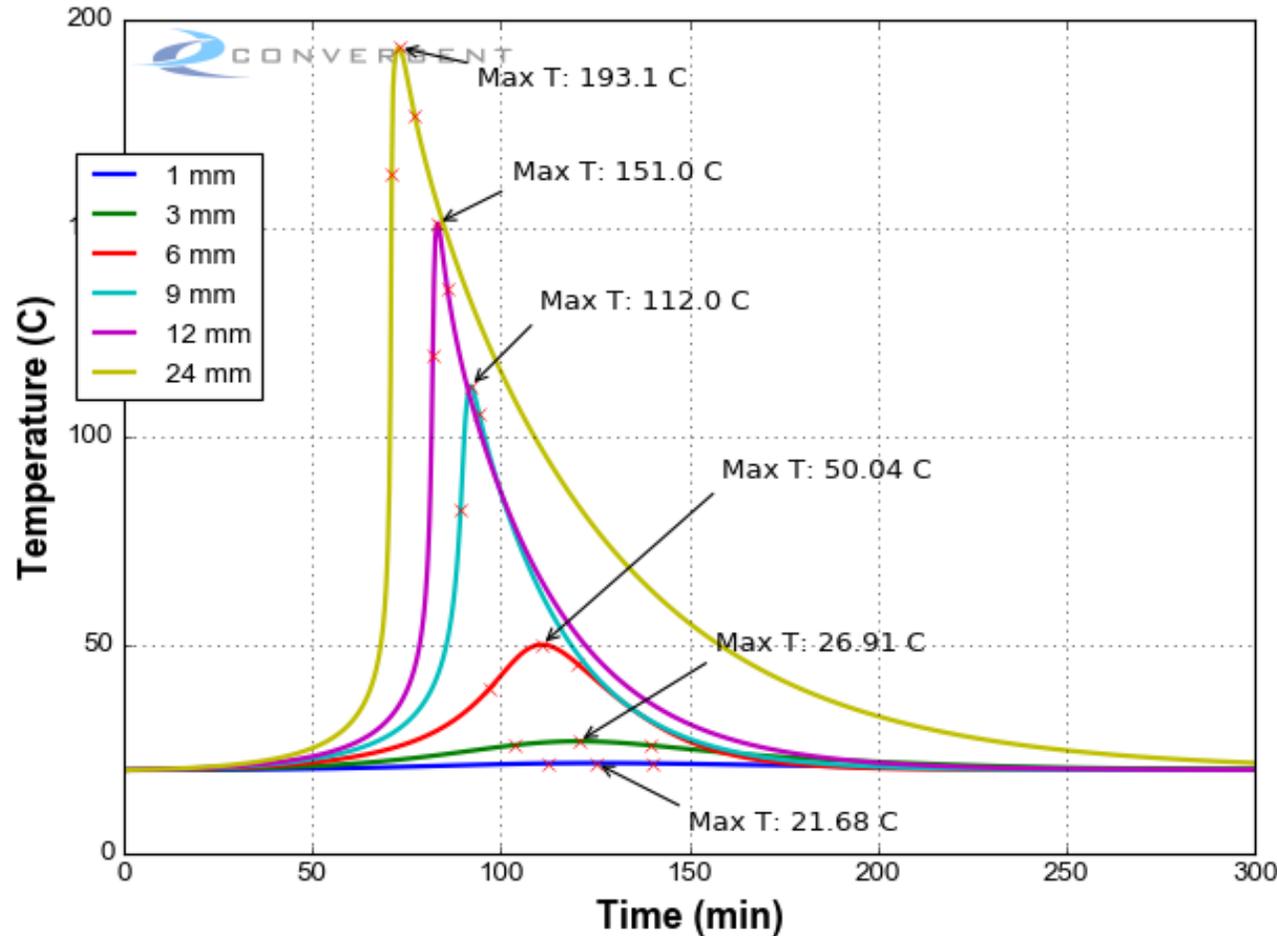
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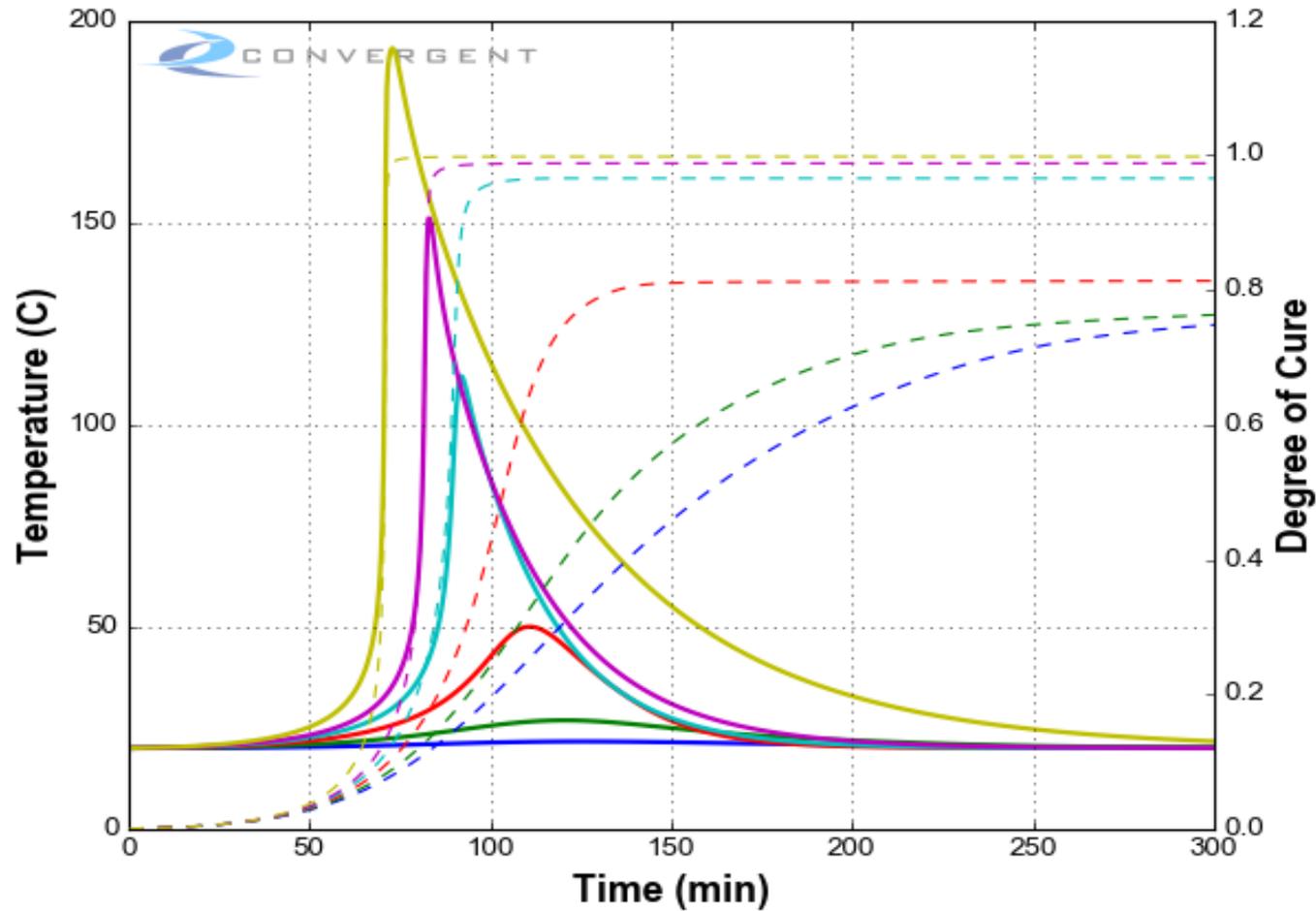
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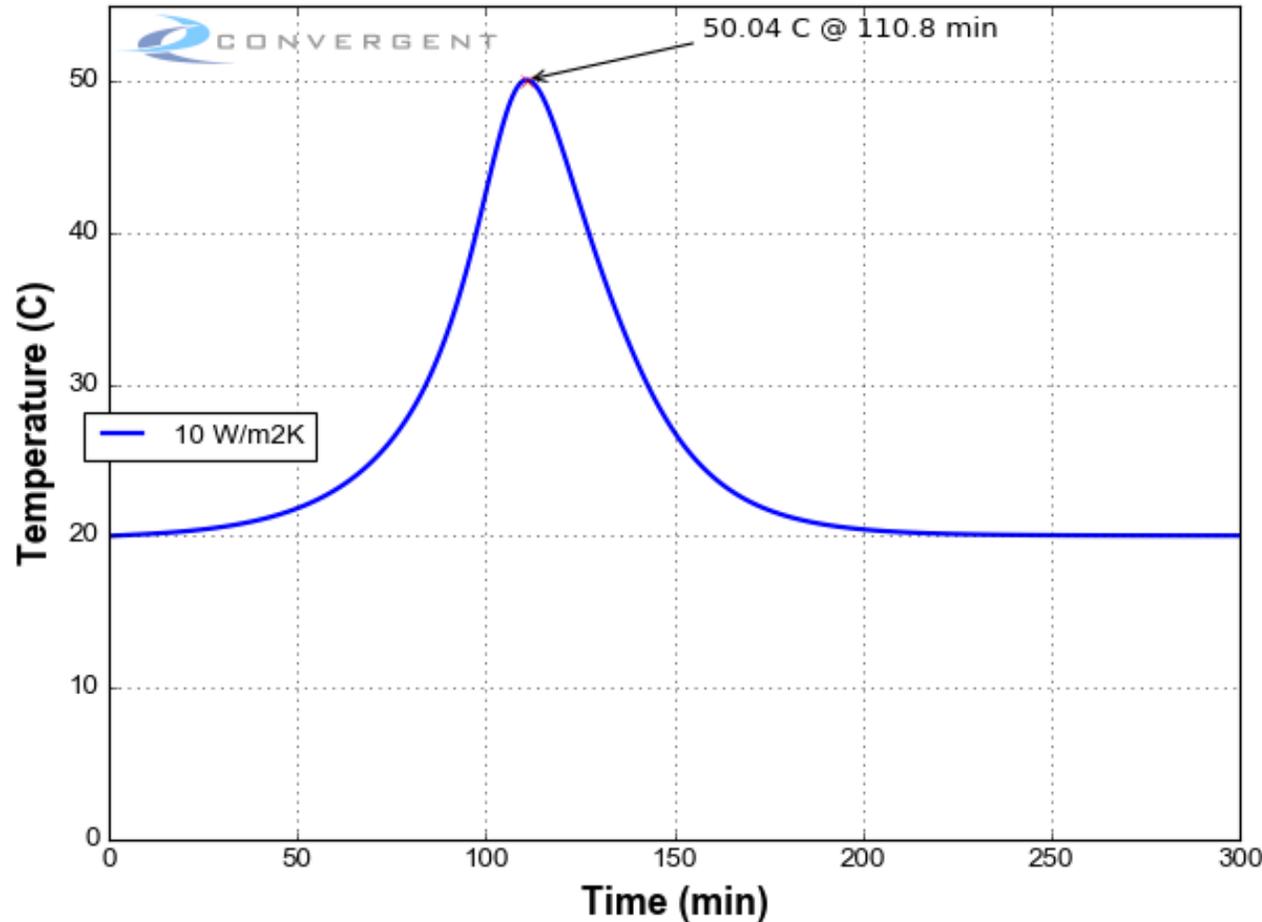
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- Airflow (convection)

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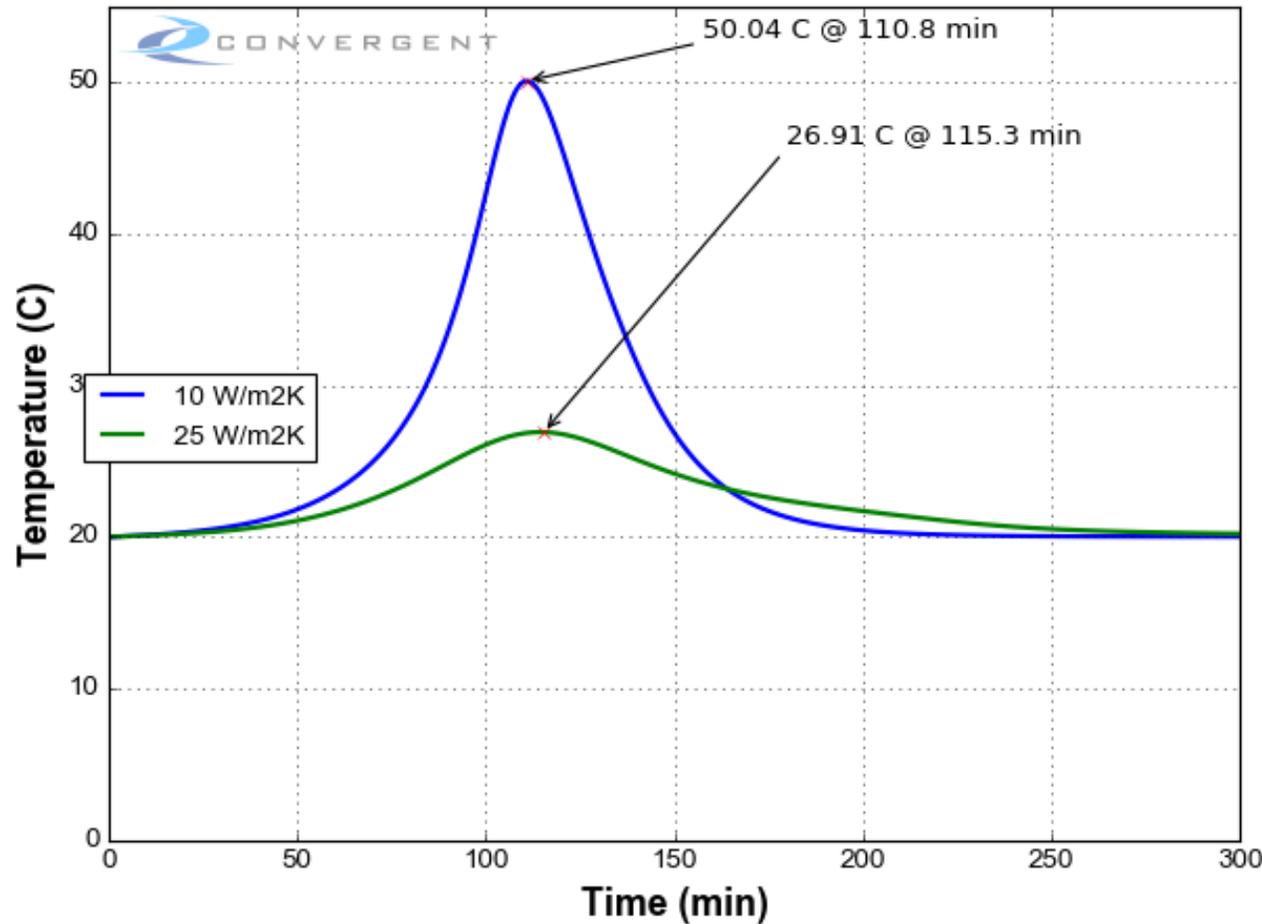
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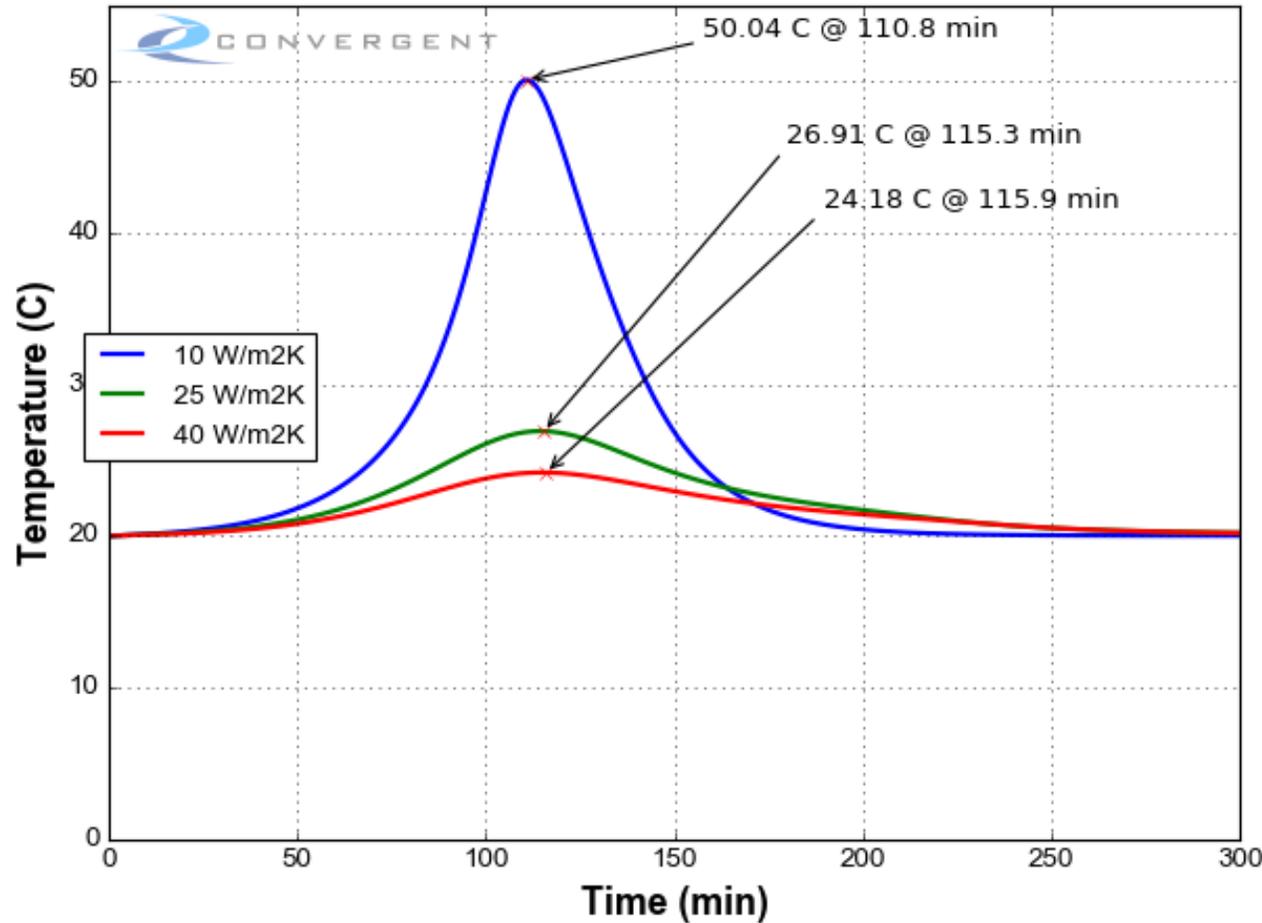
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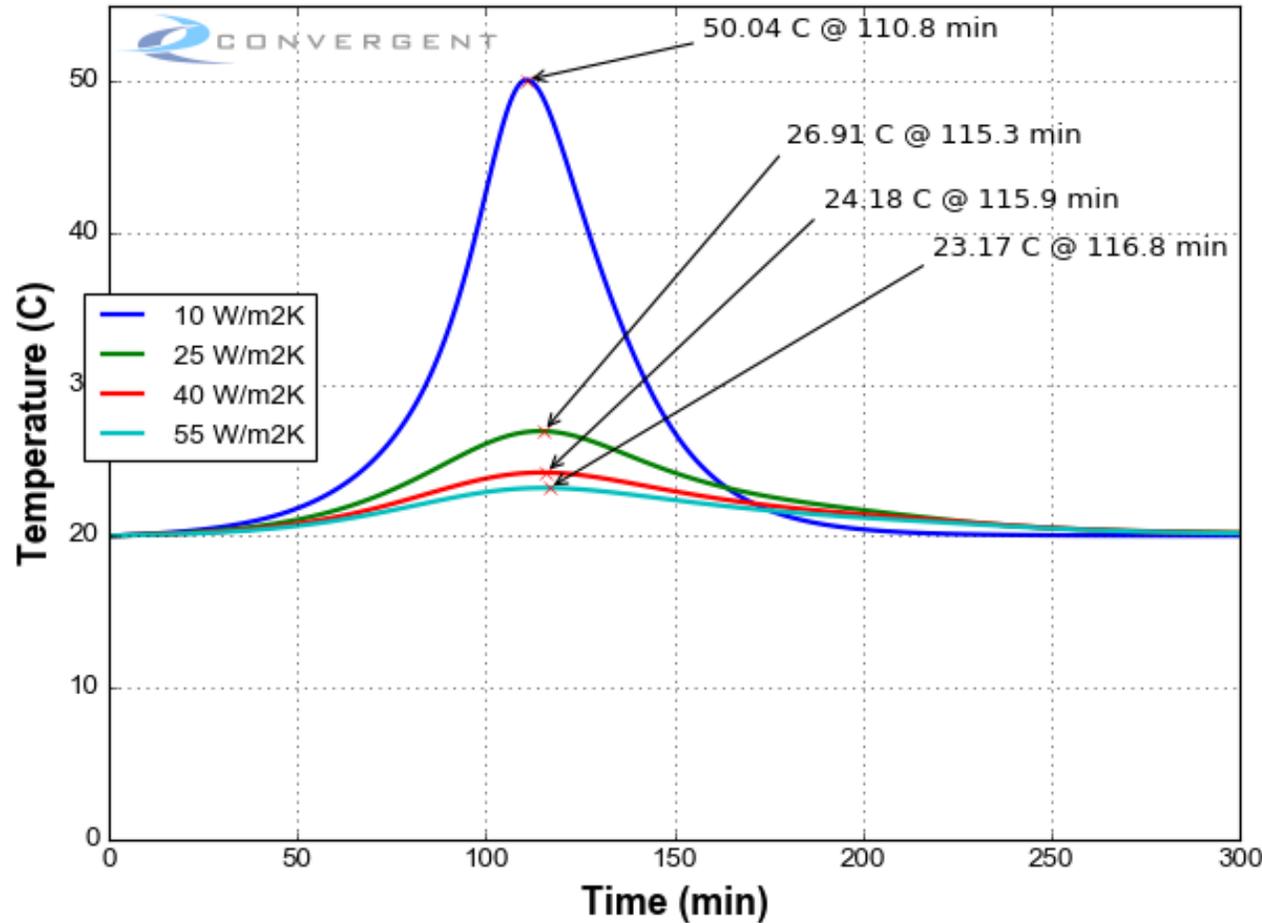
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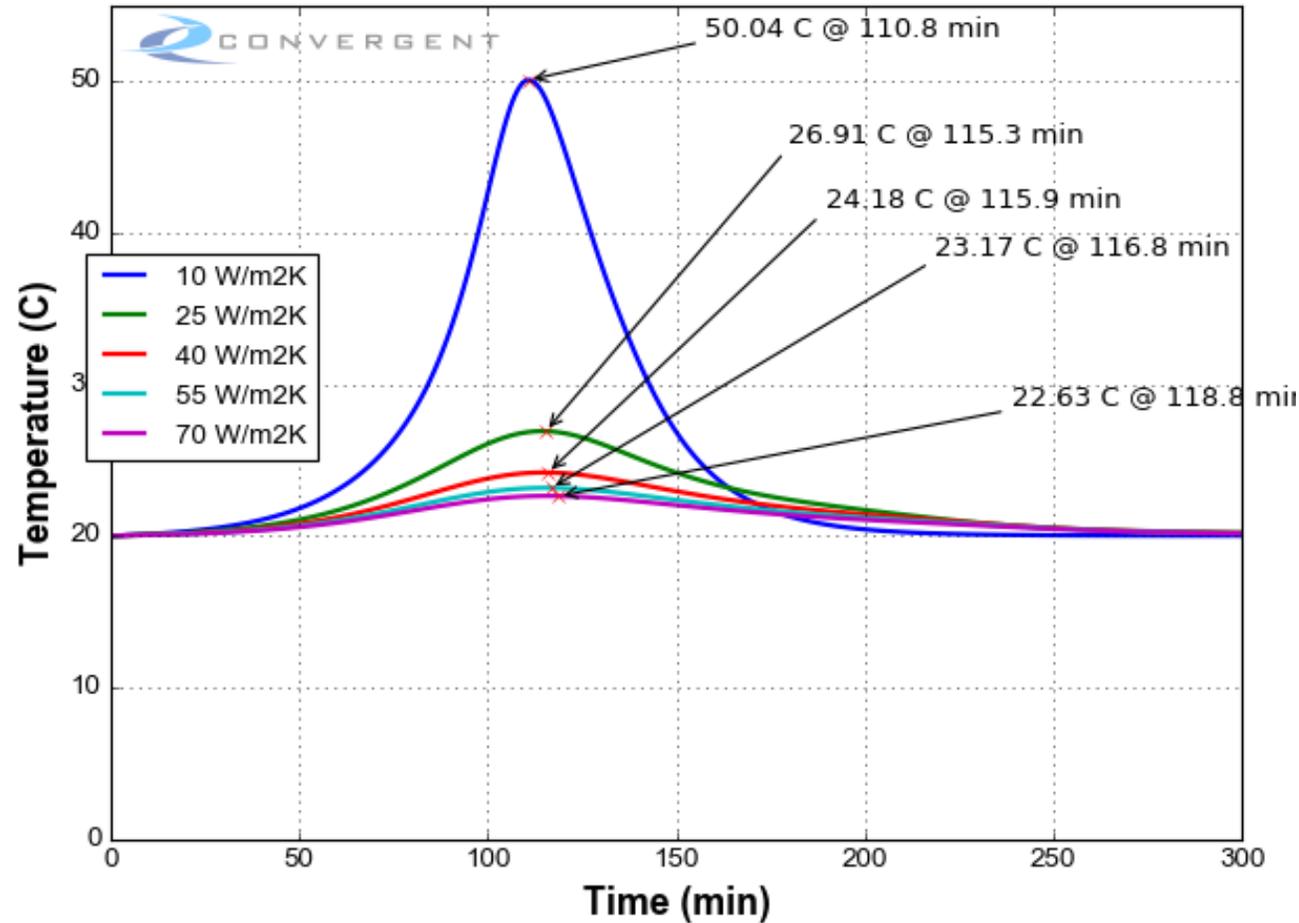
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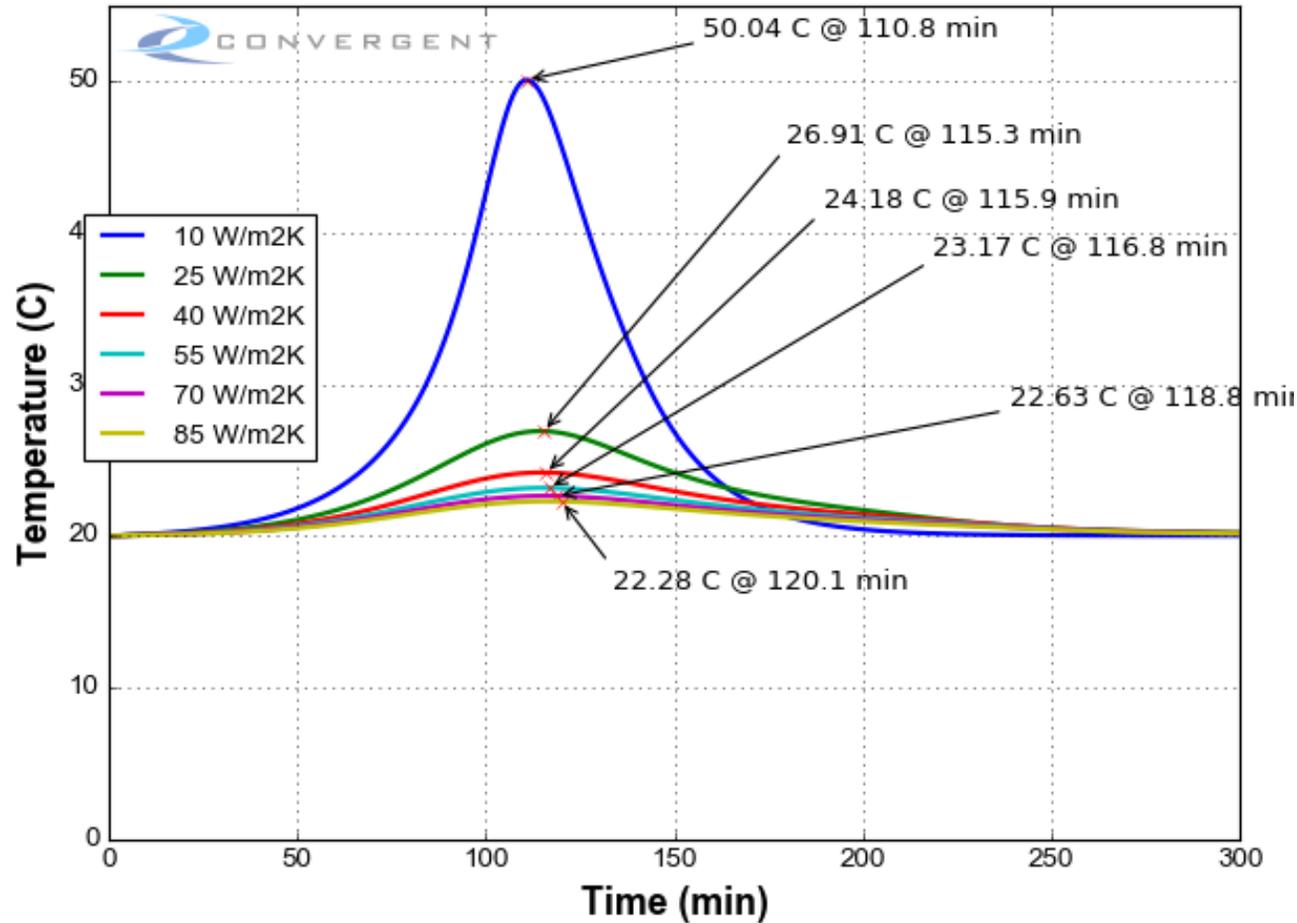
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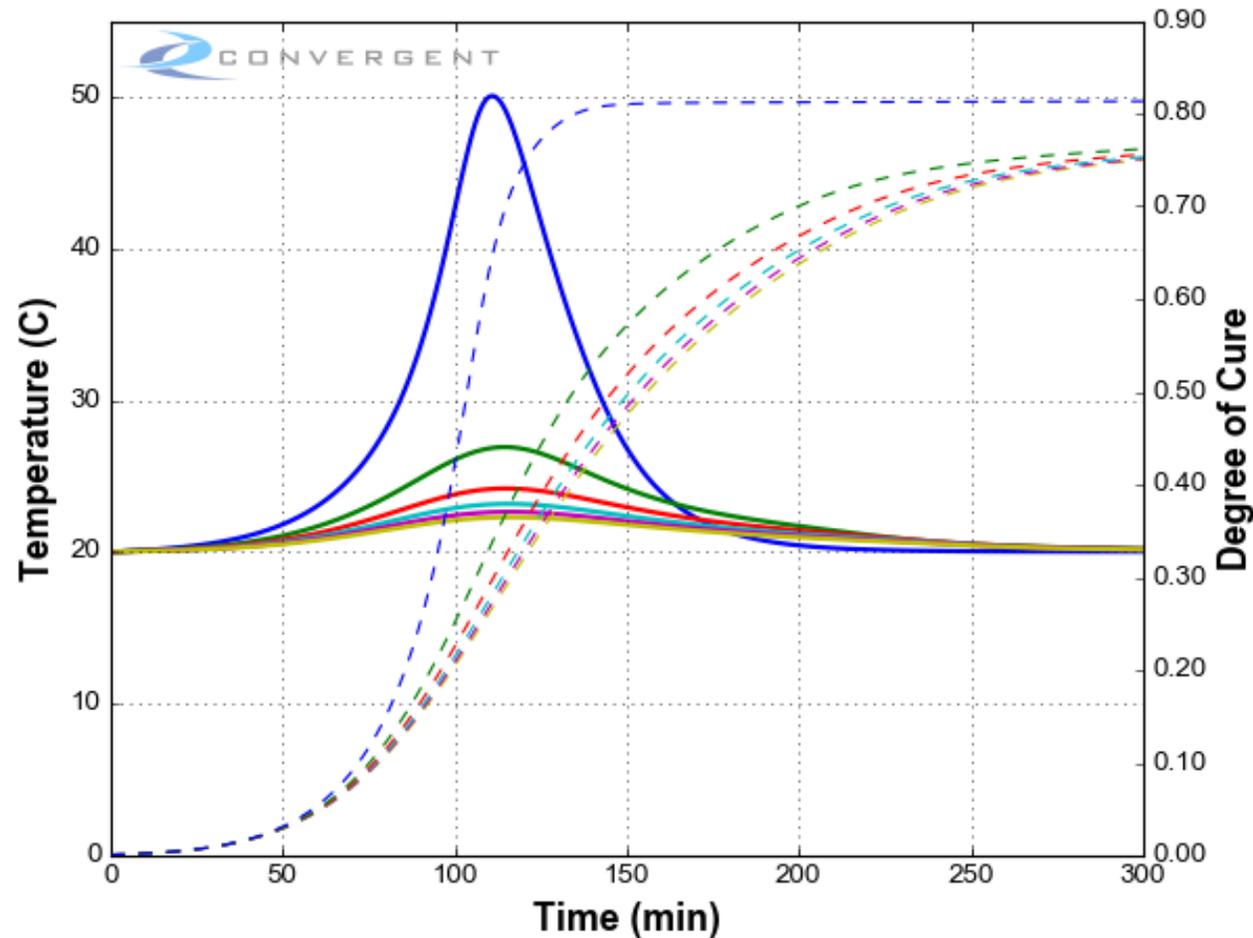
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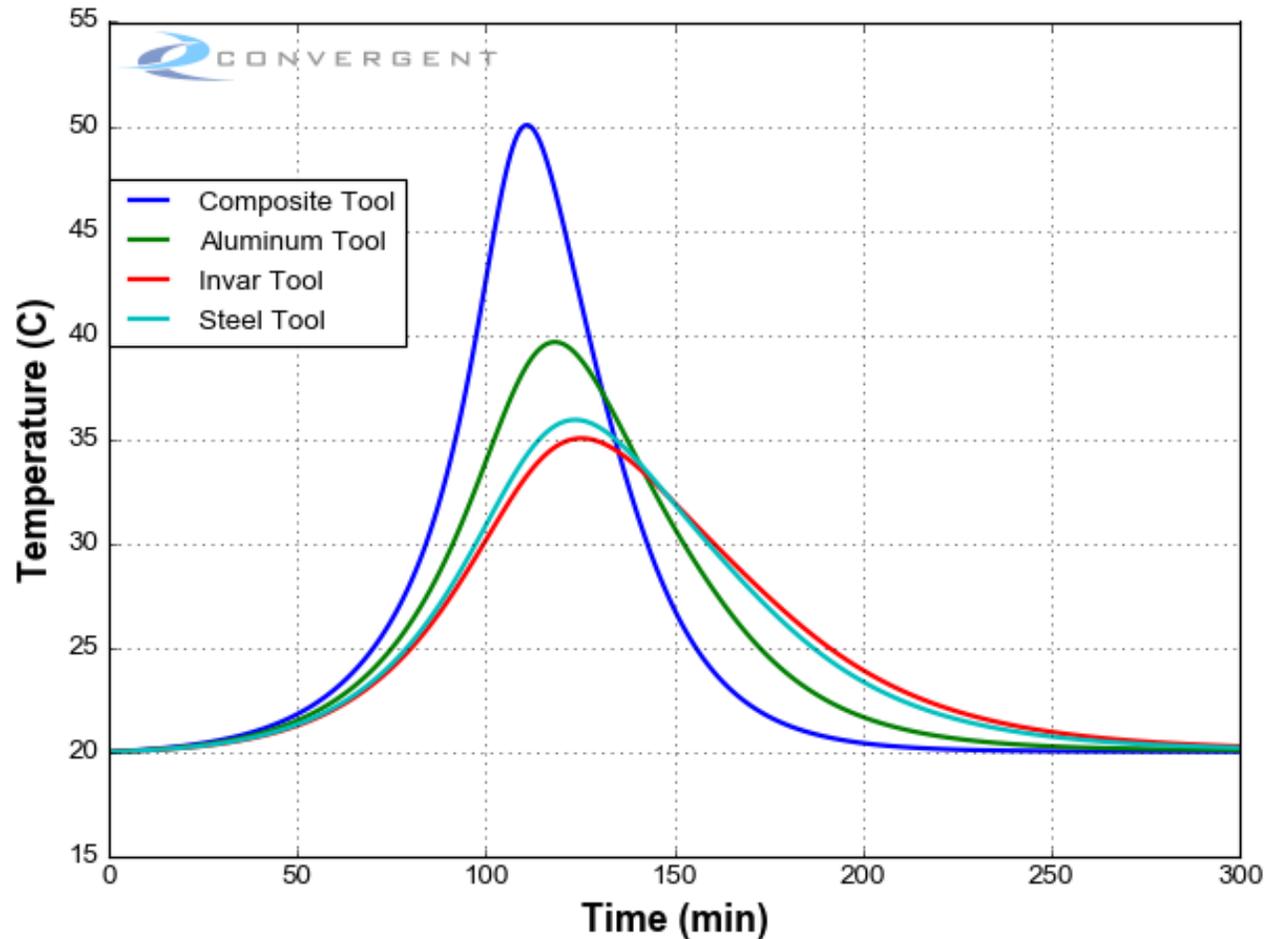
Unless otherwise stated:
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 1.25% MEKP
 6 mm composite tool
 20°C ambient air



POLYESTER RESIN CURE SIMULATION

- Tooling Material

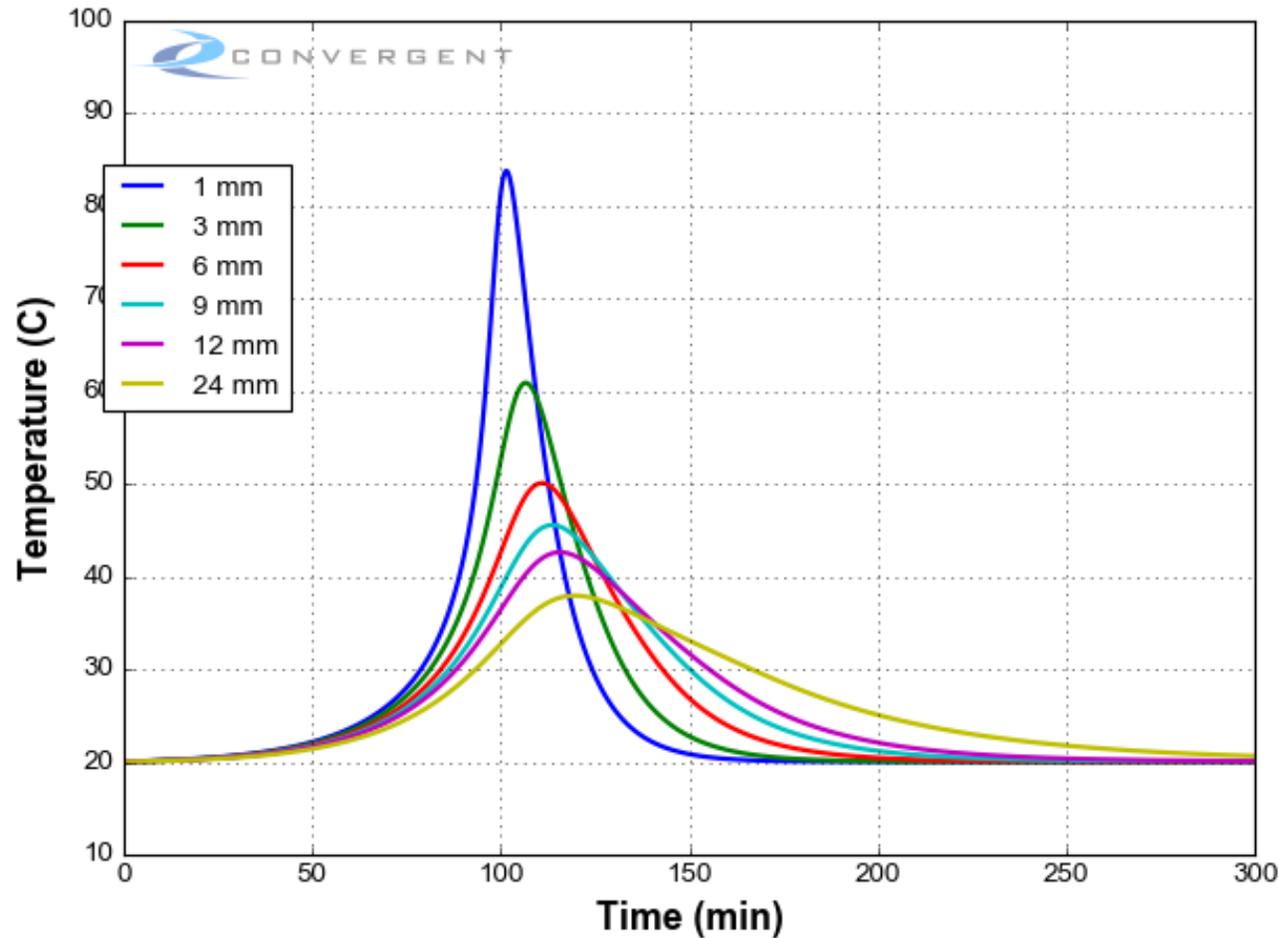
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POLYESTER RESIN CURE SIMULATION

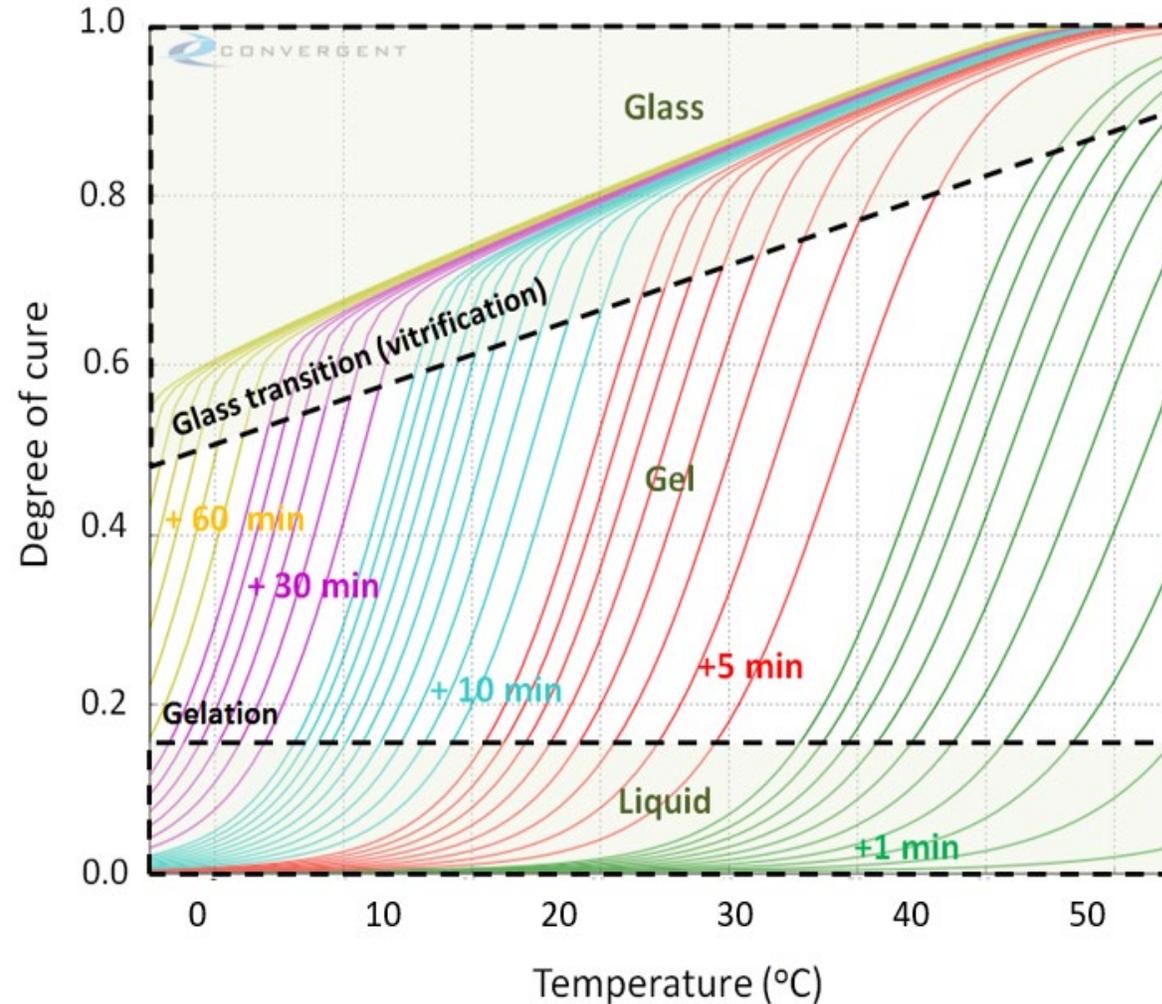
- Tooling thickness – Composite Tool

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 1.25% MEKP
 6 mm tool
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 20°C ambient air



POLYESTER RESIN CURE SIMULATION

- We haven't discussed temperature yet...



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EXPERIMENTAL STUDY - EFFECT OF AMBIENT TEMPERATURE

- Material:
 - Polyester material: Aropol CL 70502-25 Resin & Luperox DDM-9 Initiator 1.25 Vol%

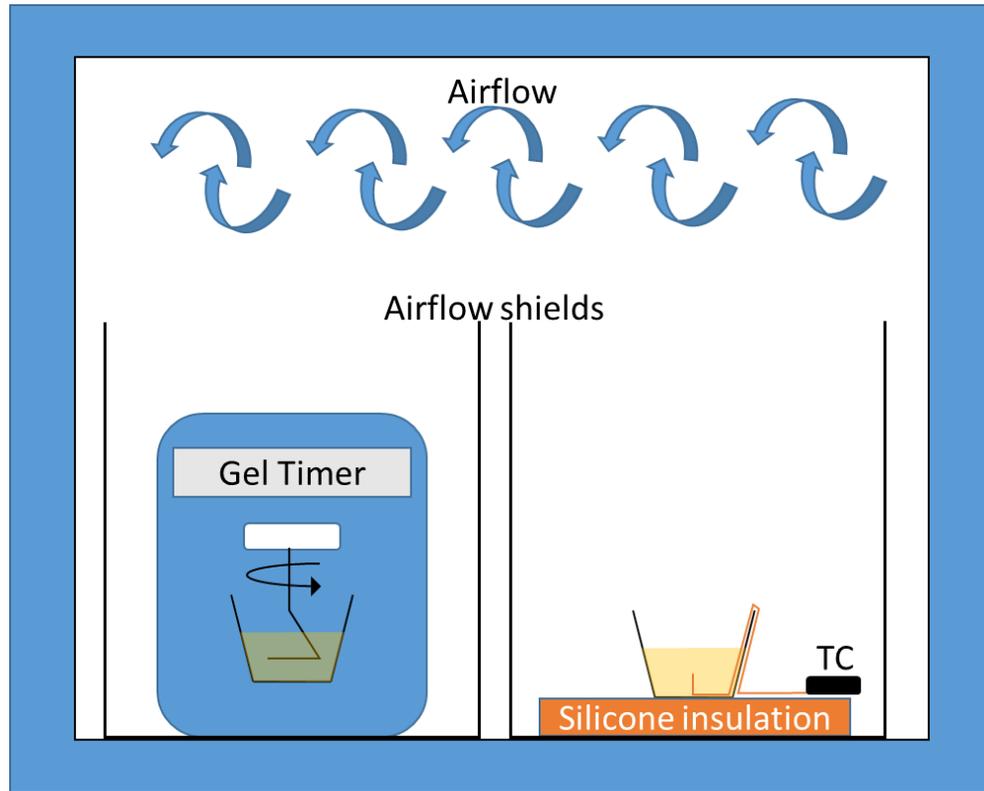
- Method:
 - 28.8 g of resin mixed and placed in an aluminum cup (thickness of 12.7 mm), repeated X2
 - One cup placed in an environmental chamber
 - One cup placed in gel timer, that was also in the environmental chamber
 - Thermocouple placed at the centre of the resin to log temperature data
 - Thermocouple used to record ambient temperature
 - Samples held at the following ambient temperatures:
 - 0 °C
 - 6 °C
 - 10 °C
 - 14 °C
 - 18 °C
 - 22 °C
 - 26 °C



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EXPERIMENTAL STUDY - EFFECT OF AMBIENT TEMPERATURE



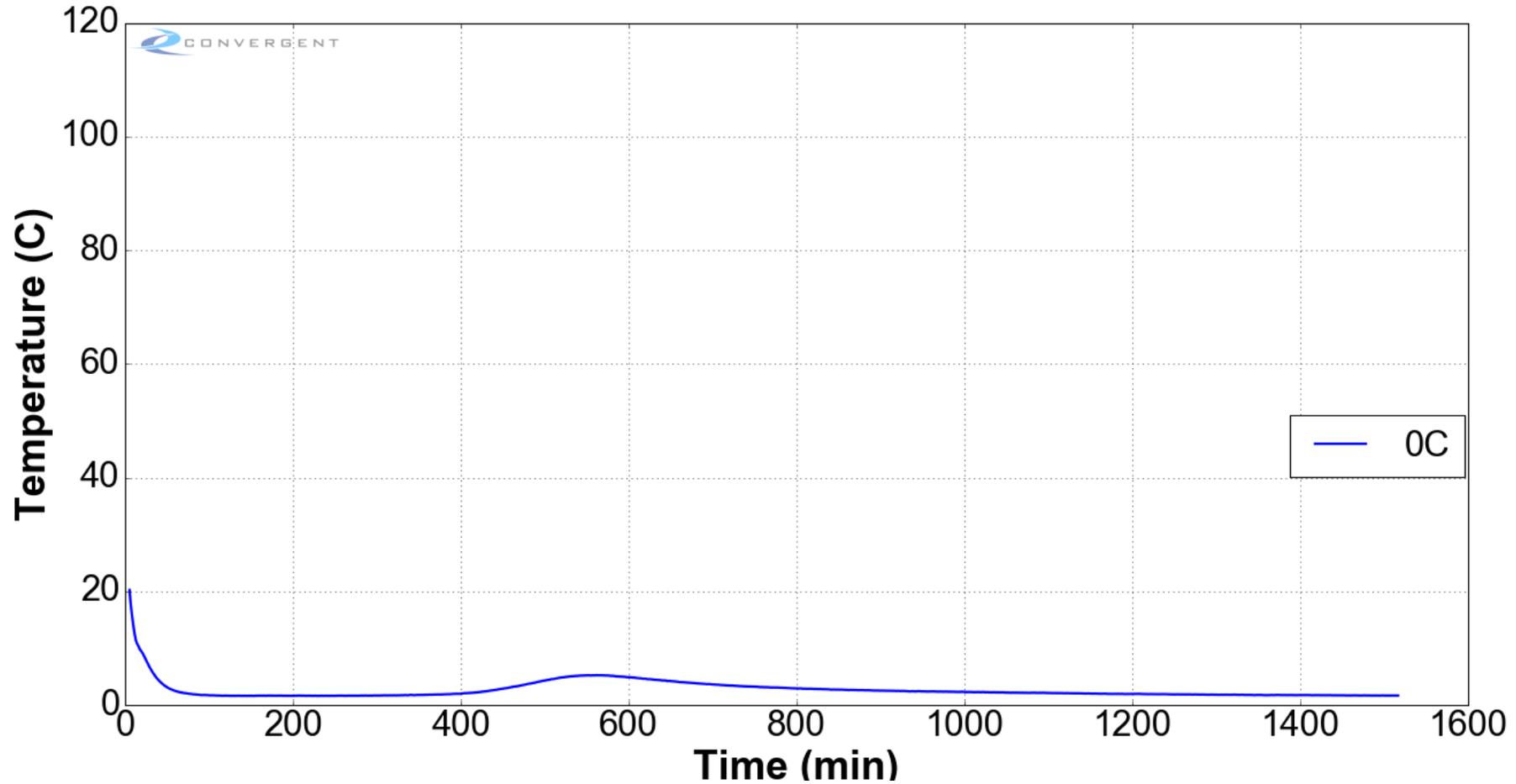
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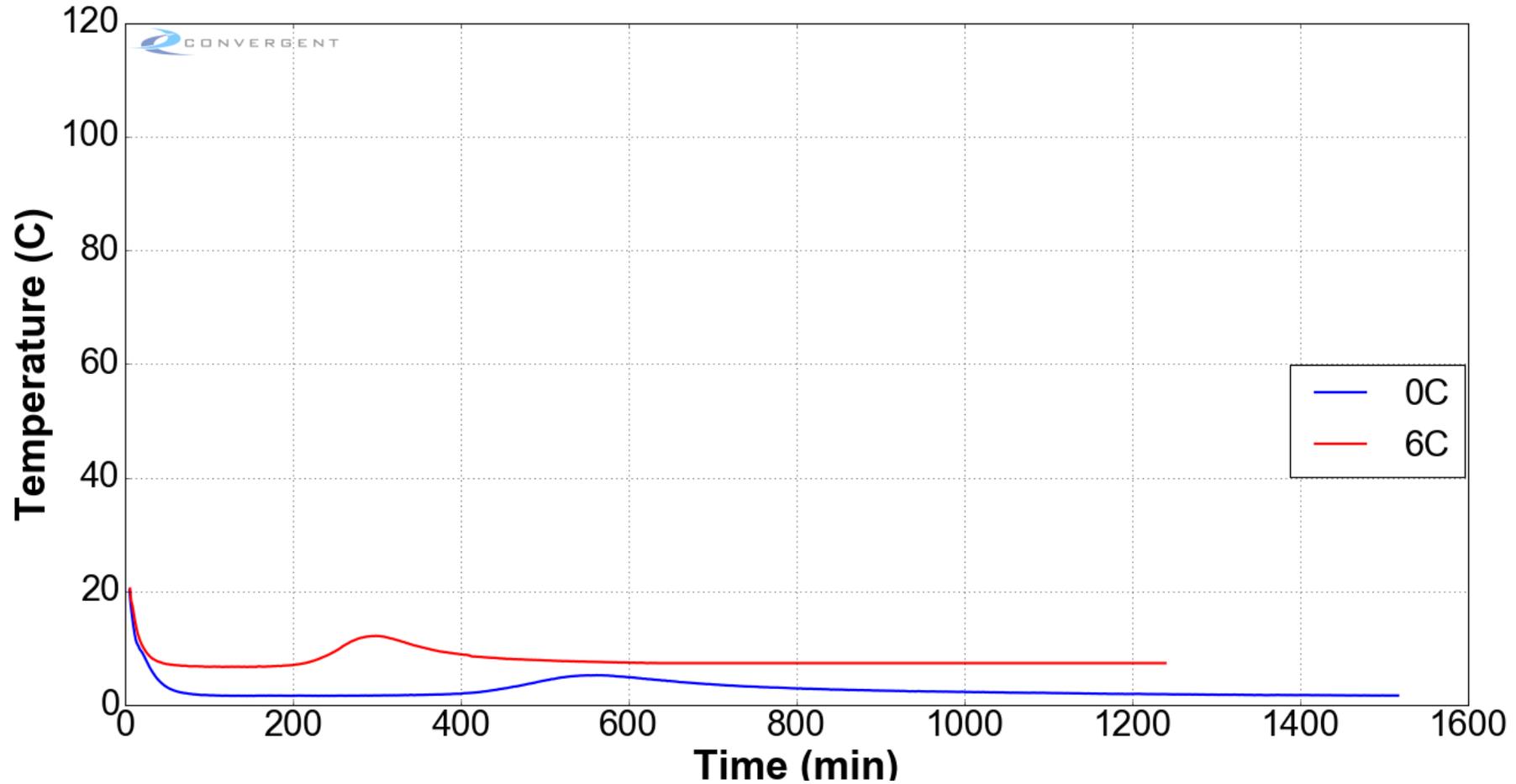
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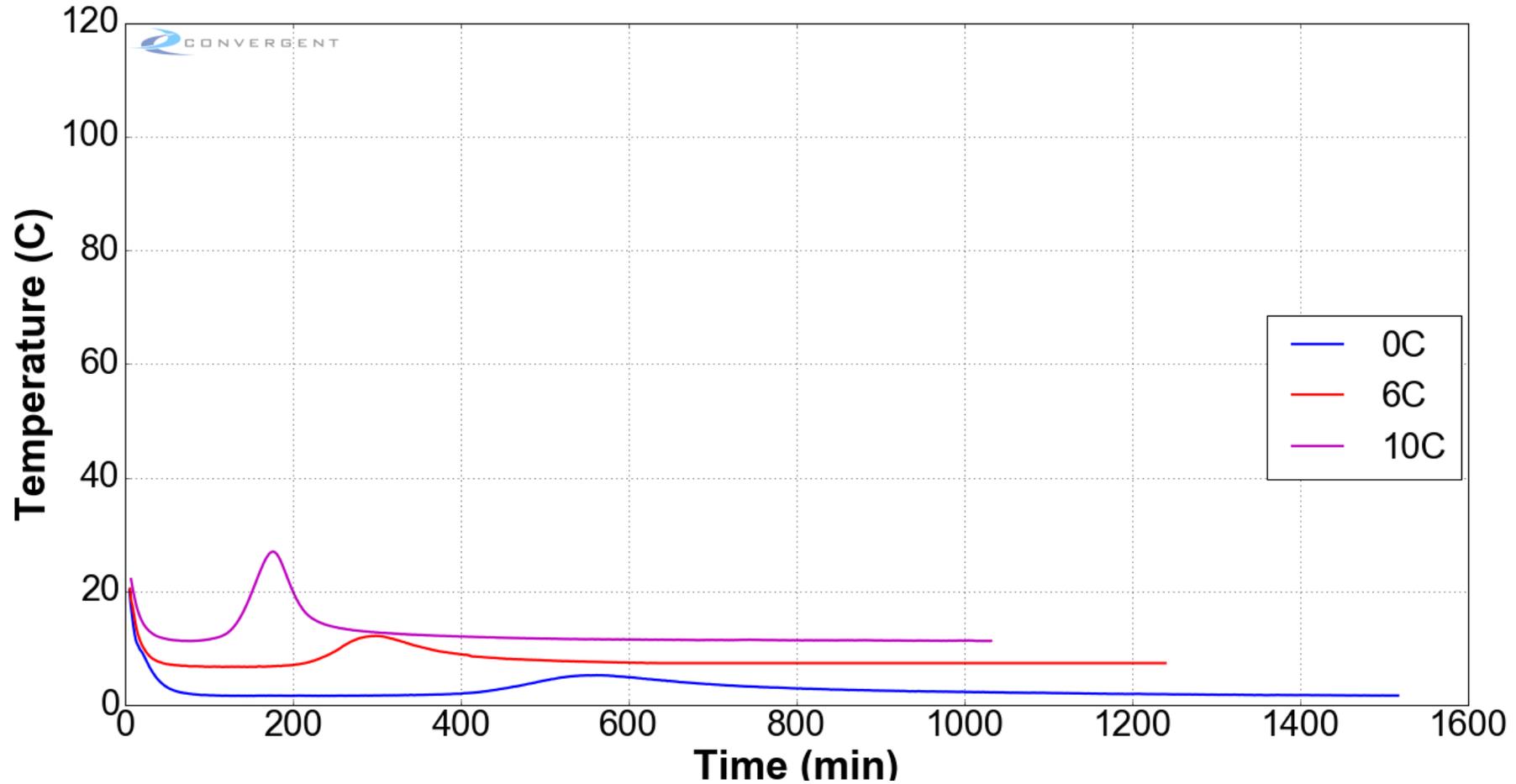
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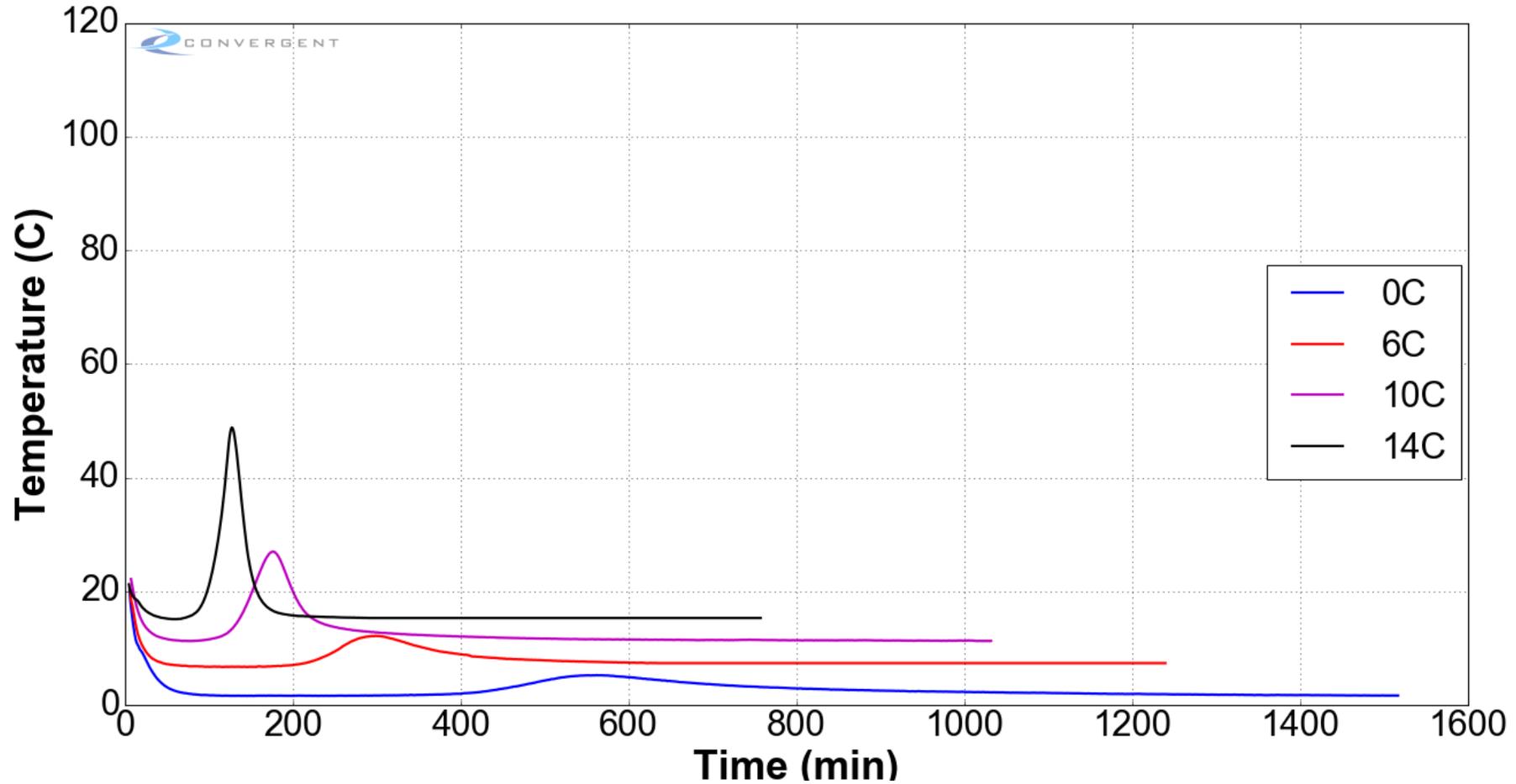
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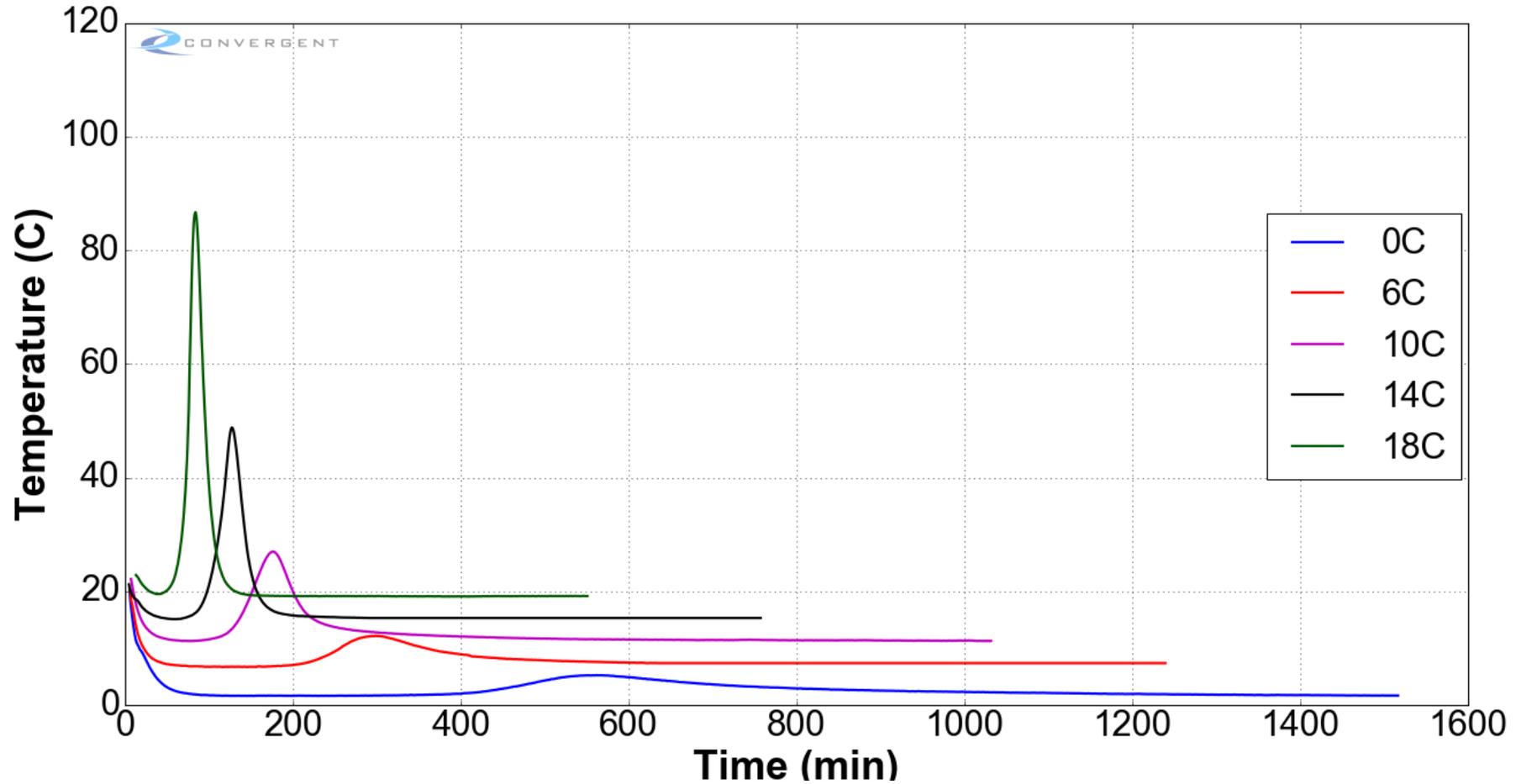
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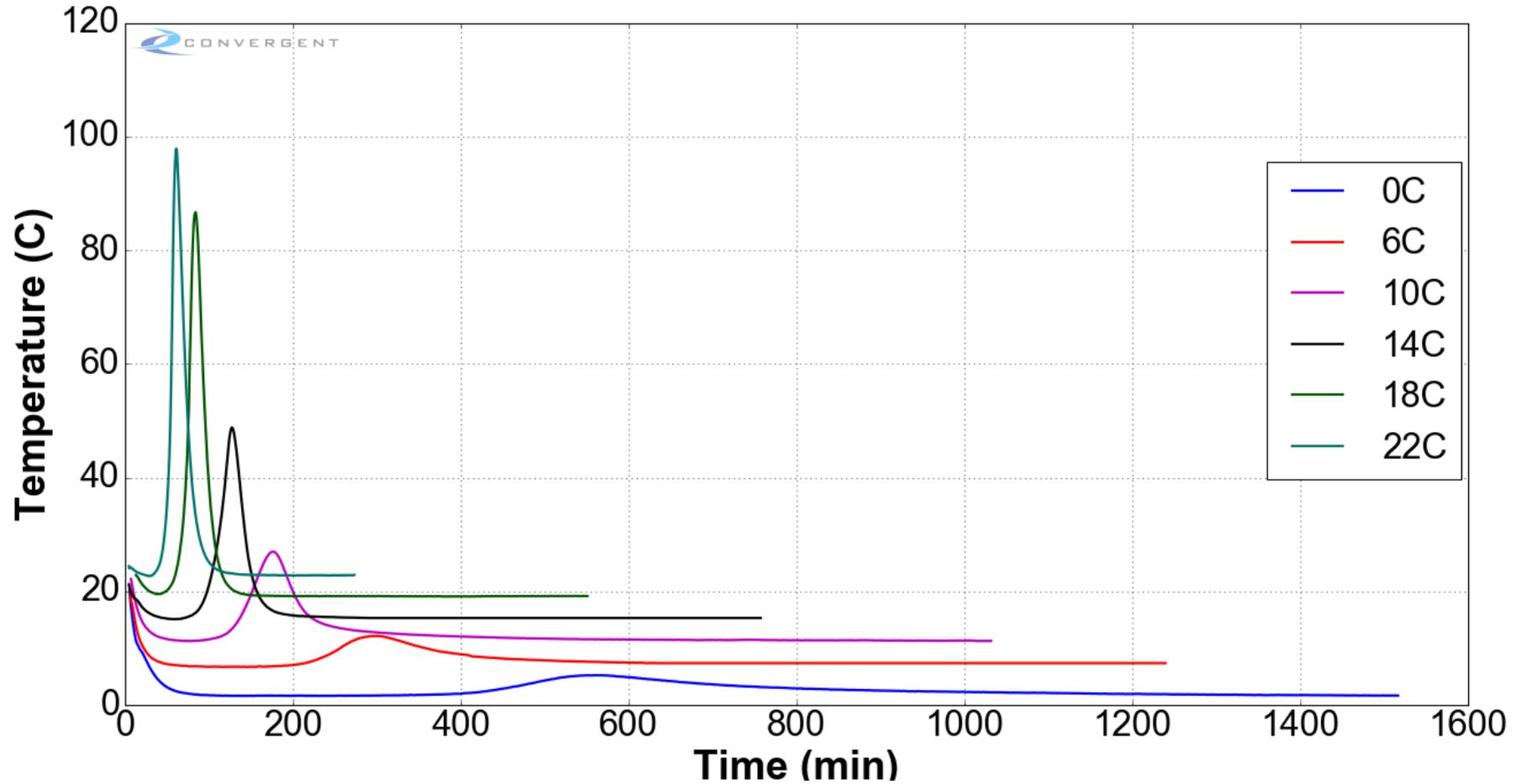
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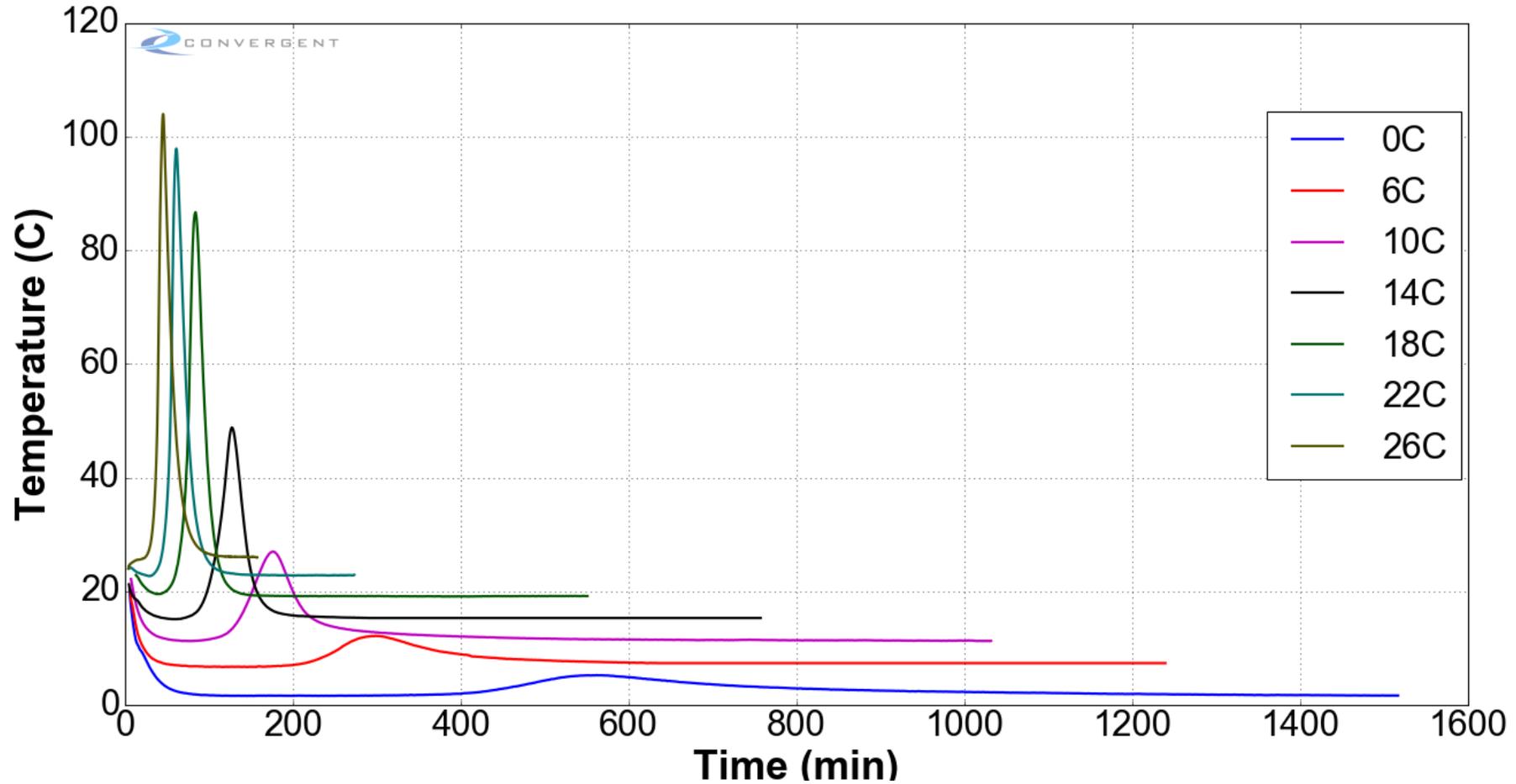
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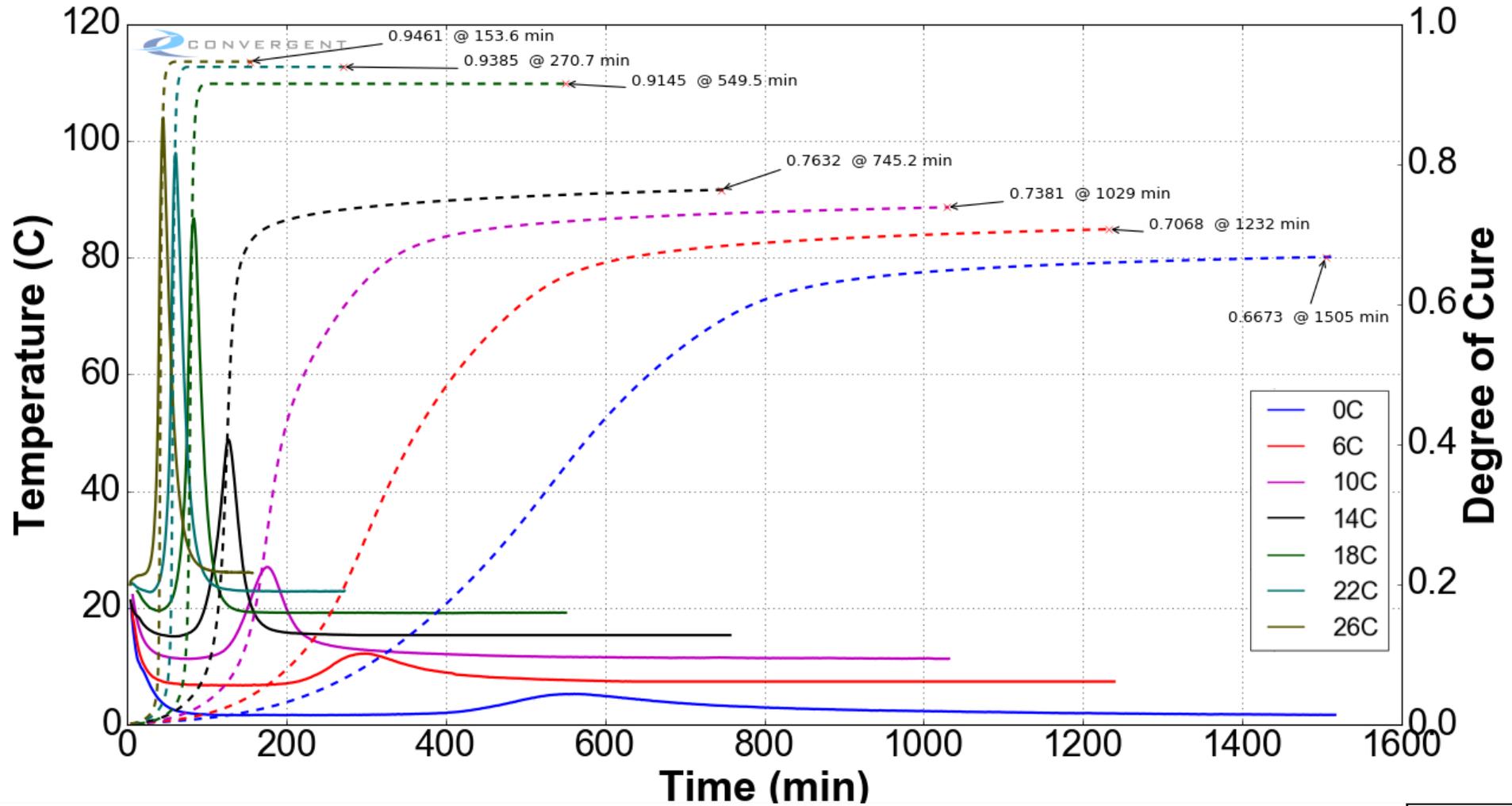
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EXPERIMENTAL STUDY - EFFECT OF AMBIENT TEMPERATURE



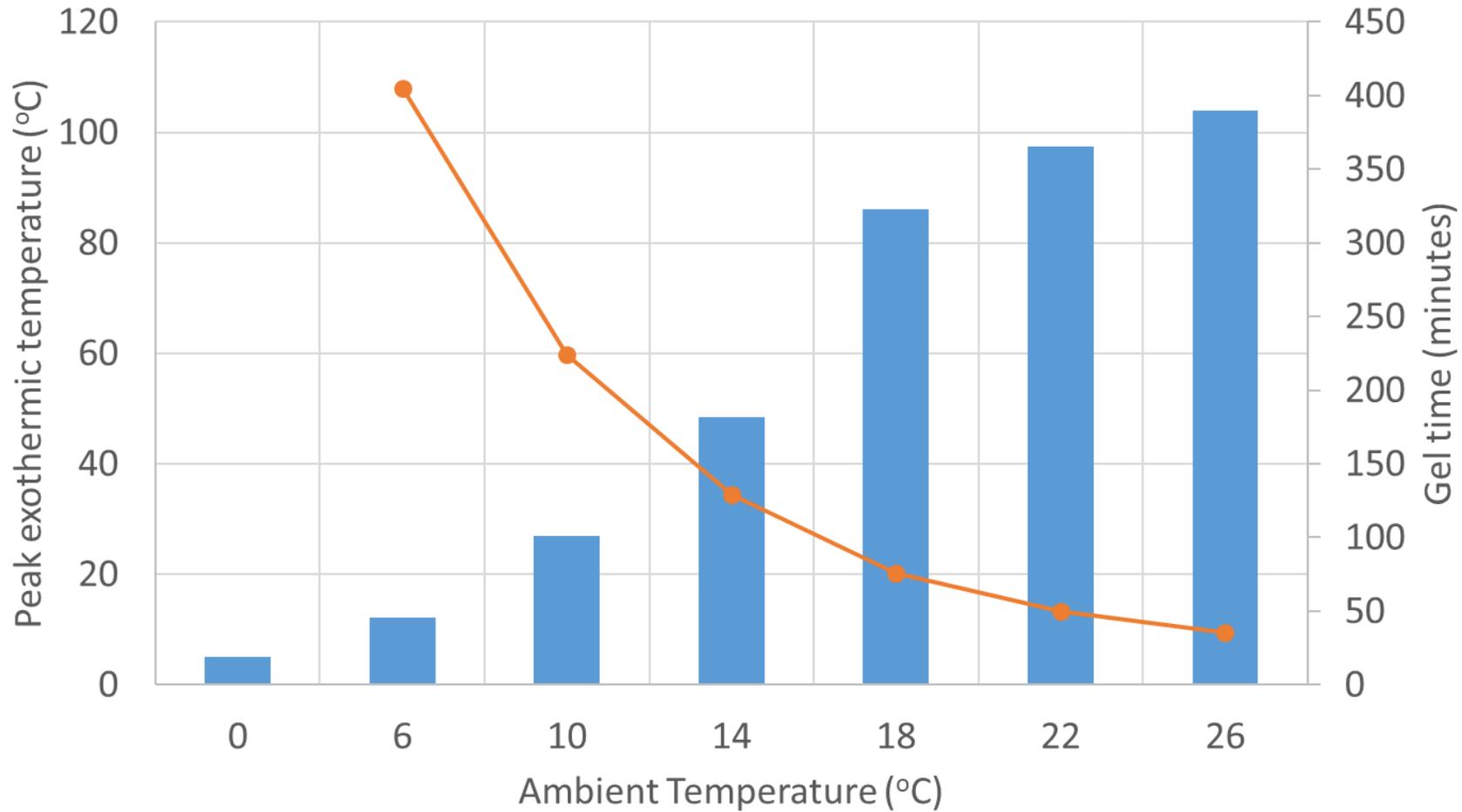
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EXPERIMENTAL STUDY - EFFECT OF AMBIENT TEMPERATURE



■ Peak exothermic temperature ● Gel time

EXPERIMENTAL STUDY

- Key take aways from these results:

As

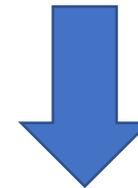


Ambient air temperature



Peak exotherm temperature

Degree of cure



Gel time

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INDUSTRIAL CASE STUDY

- Several companies in the Okanagan (BC) reported issues with inconsistent product quality depending on the season in which they were manufactured
 - More warranty claims from products built in the winter vs. summer
 - ...parts shipped to across the Pacific Ocean in a shipping container... arrived in a different shape...
- Glass fibre-polyester used - sourced from same manufacturer in each case
- Parts were cured at *ambient* air temp

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MANAGING THE CURE

- *What can we do to address this?*
- Not practical to use a convection oven for large parts
- In-mould temperature control can be expensive, challenging with composite tooling
- Strategies
 - Forced air (heater)
 - Infrared heater
 - Tent around the part and heat with heater
 - Careful with this, could result in uneven temperature distribution
 - Insulation/blanket
 - Heat is being generated, just a matter of keeping it in
 - Heated blanket

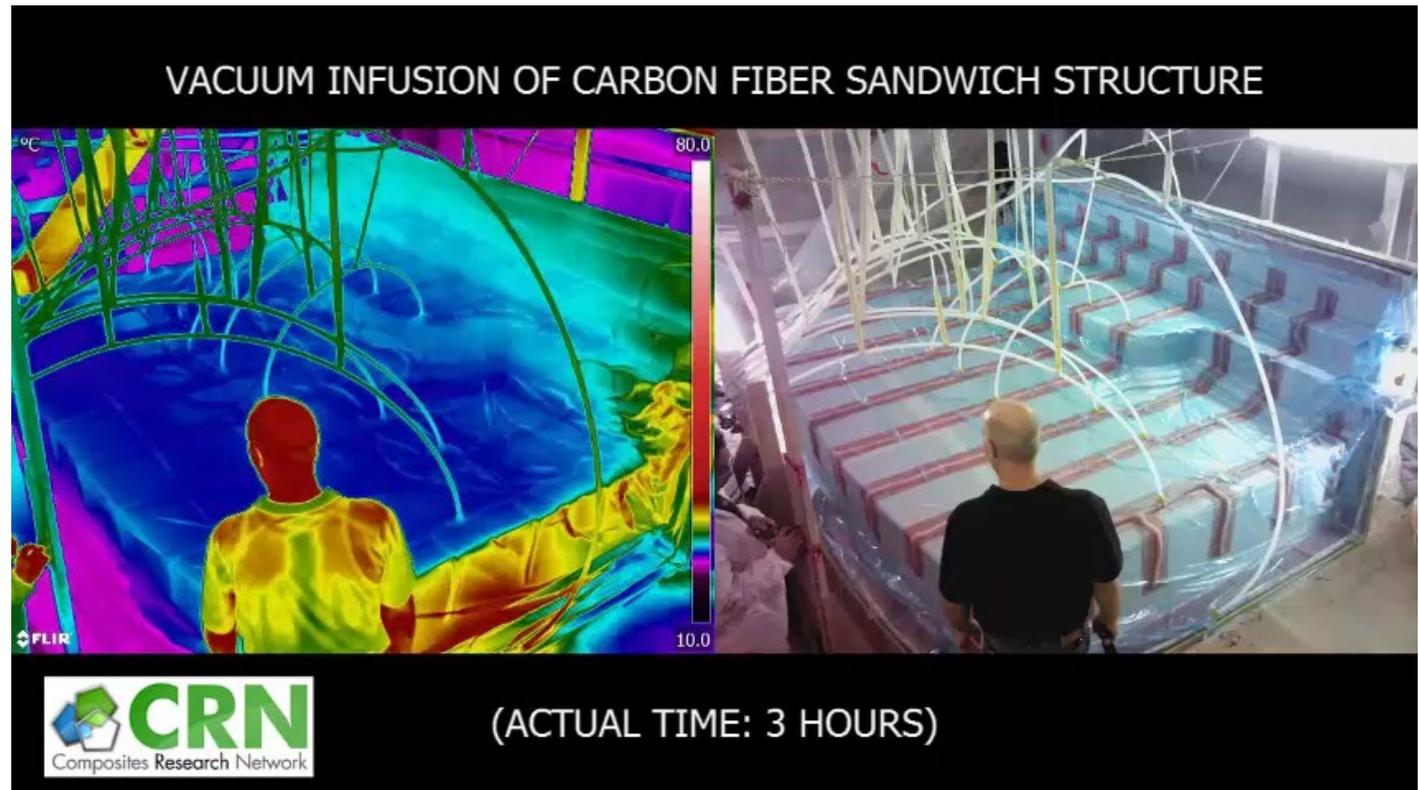


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MANAGING THE CURE

- Infusion of stairs/deck for 145' luxury yacht



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Thank you for joining us!

***Keep an eye out for announcements on the next AIM events
And don't forget to visit the KPC for more information:***

<https://compositeskn.org/KPC>

Questions?

For more information on future dates and times visit:

compositeskn.org